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Towards a Predictive Capability for Management of the Lake Winnipeg Fishery

By W. Lysack, 1986

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Natural Resources
Fisheries

CORRECTIONS TO MS REPORT 86-15: TOWARDS A PREDICTIVE CAPABILITY FOR MANAGEMENT OF THE LAKE WINNIPEG FISHERY

Attached please find 5 pages of additions and corrections for this report.

Walt

Walt Lysack

April 16,1987

please insert this sheet at the end of Table 3

Table 3, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1982	2	7	30.26	271.71	284.29
		3	126	3.55	328.06	446.11
		4	414	1.95	344.68	522.87
		5	140	3.89	391.07	739.50
		6	80	5.40	443.19	1063.25
		7	40	6.45	478.00	1340.00
		8	20	7.39	489.10	1459.00
		9	1	-	448.00	1120.00
			$\Sigma = 828$			
	1983	2	2	1.23	235.00	115.00
		3	28	17.28	331.93	388.21
		4	64	39.51	365.13	560.31
		5	33	20.37	418.12	866.97
		6	22	13.58	446.18	1056.82
		7	10	6.17	506.00	1564.00
		8	2	1.23	541.00	1910.00
		10	1	0.62	618.00	3000.00
			$\Sigma = 162$			

Table 17. Relationships of instantaneous maturity rates and the growth parameters of Lake Winnipeg stocks.

Species	Lake	Correlations					
		Exponential growth rate			P		
		Y=a+b·X[a]	R	Test F. value and d.f.	Y=a+b.X[b]	R	Test F value and d.f.
Sauger	North basin	Y=-2.409+46.966X[c]	0.985	67.40(1,2)	Y=16.561-3.249X	0.352	0.42(1,3)
	South basin	Y=-0.839+24.844X	0.552	0.88(1,2)	Y= 3.313-0.323X	0.710	3.04(1,3)
Walleye	North basin	Y= 1.323-0.767X	0.062	0.01(1,2)	insufficient data		
	South basin	Y= 2.691-11.292X	0.635	2.03(1,3)	Y=-1.315+0.543X	0.248	0.20(1,3)
Whitefish	North basin	Y= 1.747-4.359X	0.044	0.01(1,3)	Y=-1.688+0.669X	0.725	3.33(1,3)

a. Y= instantaneous maturity rate, X = exponential growth rate

b. Y= instantaneous maturity rate, $X = P = \log_e(L_\infty \cdot K)$

c. significant at P=0.05, 1979 outliner datum deleted.

Table 13. Walford plots of walleyes, saugers and whitefish from the major areas of Lake Winnipeg, 1979-83.

Species	Area	Year	$L_{t+1}=a+bL_t$	L_∞ (mm)	R	Test F. ratio and d.f.
Sauger	North basin	1979	Y=105.526+0.738X	402	0.861	34.48(1,13)
		1980	Y=100.075+0.765X	425	0.987	254.69(1.7)
		1981	Y=130.400+0.686X	415	0.903	44.26(1,10)
		1982	Y=120.168+0.726X	439	0.968	119.32(1.8)
		1983	Y= 97.358+0.799X	484	0.992	323.22(1,5)
	Channel	1979	Y= 90.417+0.750X	361	0.980	145.45(1,7)
		1980	Y= 73.771+0.799X	367	0.972	84.29(1,5)
		1981				
		1982	Y= 61.416+0.876X	495	0.989	270.35(1,6)
		1983	Y= 71.927+0.848X	473	0.977	107.09(1,5)
	South basin	1976	Y=102.399+0.787X	481	0.796	8.63(1,5)
		1977	Y= 65.692+0.880X	547	0.993	380.03(1,5)
		1978	Y= 67.085+0.884X	578	0.988	81.68(1,2)
		1979	Y=248.188+0.178X	301	0.826	8.57(1,5)
		1980	Y= 98.822+0.706X	334	0.964	91.81(1.7)
		1981	Y= 78.020+0.788X	368	0.999	4118.43(1,5)
		1982	Y=118.492+0.696X	390	0.996	351.73(1,3)
		1983	Y= 73.873+0.848X	486	0.991	216.77(1,4)
Walleye	North basin	1979	Y= 26.534+0.999X	∞	0.987	151.32(1,4)
		1980	Y= 95.007+0.811X	500	0.951	28.13(1,3)
		1981	Y=137.280+0.694	449	0.997	643.25(1,4)
		1982	Y=120.807+0.763X	510	0.997	358.86(1,2)
		1983	Y= 38.284+0.987X	∞	0.999	1699.02(1,5)

Table 15. Maturity curves of female walleyes, saugers and whitefish from major areas of Lake Winnipeg, 1979-83.

Species	Lake	Year	Maturity curve $-\log_e \frac{(K-Y)}{Y} = bX_o + bX$	Age at 50% mature (years)	Correlation coefficient	Test F ratio and d.f.
Walleye	North	1979	Y=7.43+1.07X	6.92	0.970	64.02(1,4)
		1980	Y=11.00+1.46X	7.55	0.895	12.07(1,3)
		1981	Y=6.642+0.904X	7.34	0.975	58.75(1,3)
		1982		sample size too small		
		1983	Y=-11.869+1.551X	7.65	0.956	21.49(1,2)
	South	1979	Y=- 5.43+0.720X	7.54	0.948	35.25(1,4)
		1980	Y=-5.896+1.100X	5.36	0.968	29.92(1,2)
		1981	Y=-9.977+1.891X	5.28	0.997	291.49(1,2)
		1982	Y=-10.913+1.942X	5.62	0.985	66.07(1,2)
		1983	Y=-9.315+1.706X	5.46	0.989	45.06(1,1)*
Sauger	North	1979	Y=-3.960+1.022X	3.87	0.991	109.07(1,2)
		1980	Y=-5.874+1.101X	5.34	0.973	71.33(1,4)
		1981	Y=-3.309+0.776X	4.26	0.977	82.52(1,4)
		1982	Y=-8.009+1.422X	5.63	0.970	31.53(1,2)
		1983	Y=-8.417+2.188X	3.85	0.997	186.30(1,1)
	South	1979	Y=-3.52+1.37X	2.57	0.956	10.70(1,1)*
		1980	Y=-5.427+1.462X	3.71	0.956	21.11(1,2)
		1981	Y=-8.351+1.724X	4.82	0.985	100.24(1,3)
		1982	Y=-8.846+1.740X	5.08	0.937	14.34(1,2)*
		1983	Y=-8.671+2.249X	3.86	0.977	21.38(1,1)*

(incomplete) cohorts of south basin saugers contributed relatively large biomasses (Fig. 44).

Cohort biomasses of south basin walleyes and saugers were reconstructed assuming that predicted trawl CUE values (Table 23) were accurate indicators of variable recruitment i.e., for each cohort, $N_o = 1000 + (1000 \cdot \text{predicted trawl CUE})$. A constant value of 1000 was included in each N_o to account for negative predicted trawl CUE values. Thus, the first model depicts cohort biomass assuming constant recruitment and the second model depicts cohort biomass as a function of variable recruitment.

In each case, the amount of spawning female biomass escaping the fishery during each year from 1979 to 1983 was estimated by: Spawn B - (% comm·Spawn B) (Table 28). In southern Lake Winnipeg, escaped female walleye spawning biomass declined drastically from 1979-1982 and increased in 1983. Spawning walleye biomass in the north basin was higher during each year from 1979-1982 but declined over the long term. From 1979 to 1981, escaped female sauger spawning biomass increased in the south basin and decreased in the north basin. In 1982 and 1983, northern sauger spawning biomass was higher but suffered substantially higher removal rates. Southern sauger spawning biomass was extremely low in 1982 and improved drastically in 1983. Whitefish spawning biomass remained relatively constant during the five year period but a high removal rate in 1983 decreased the escapement (Table 28).

Lysack, W. 1986. Towards a predictive capability for management of the Lake Winnipeg fishery. Manitoba Department of Natural Resources Research MS Report No.86-15, 236pp.

ABSTRACT

Lake Winnipeg is a riverine system since it has a relatively short (3-4.5 years) water retention time and since the dynamics of most abiotic and biotic processes occurring in the lake are closely correlated to hydrological regimes of incurrent rivers. Rivers draining vast western and southern watersheds provide the greatest amounts of sediments and nutrients to the lake's southern basin due to increasing urbanization and agricultural development. The south basin is shallower, warmer and more eutrophic than the north basin.

The spatial distribution of commercial fishing effort is characterized by a south-north decreasing gradient in any given year. Fishing effort in all areas has increased since 1970 due to the creation of new fishery zones, the creation of new seasonal fisheries, increases in daily gillnet amount allowances and the entry of new fishermen. Catches of all species have increased as a function of fishing effort. Catches of walleyes, saugers and whitefish are theoretically regulated by a common quota. Walleye and sauger stocks are the prime species since they are more valuable ($ kg^{-1}) than whitefish. South basin fishermen are

allowed to use 3 inch mesh gillnets, channel fishermen are allowed to use 3.75 inch mesh gillnets and north basin fishermen are allowed to use 4.25 and 5 inch mesh gillnets. The south-north gradients in mesh size and fishing effort have created south-north gradients in walleye and sauger stock responses. Southern walleyes and saugers grow and mature faster than northern walleyes and saugers.

The continuing reliance of the south basin fishery on young, small, immature walleyes and saugers and the mixed stock characteristics of channel walleyes and saugers leads to a hypothesis that migration from the north basin is supporting the south basin fishery. The north basin whitefish stock is not displaying compensatory responses since it has always been exploited at a stable level of effort with 5 inch mesh gillnets.

Annual age-specific descriptions of growth, maturity and survival regimes of walleye, sauger and whitefish stocks are merely cross-sectional representations of cohort growth, maturity and survival regimes.

The development of cohort biomass is controlled by the amount of female spawning biomass that escapes the fishery and environmental variables that regulate feeding and survival of juvenile fish produced by the escaped female spawning biomass in any given year. Evidence that annual abundance of juvenile

walleyes and saugers is a function of escaped female spawning biomass, flow rates of incurrent rivers and vernal warming rates is presented. North-south differences in spawning stock size are related to north-south differences in fishing effort and mesh size.

Overexploitation and cultural eutrophication created by rivers flowing into Lake Winnipeg's south basin are eroding the stability of the percid community.

TABLE OF CONTENTS

Page

ABSTRACT .... *i*

INTRODUCTION 1

METHODS AND MATERIALS 9

Experimental netting 9
Commercial sampling 10
Calculations 10
Concurrent studies 13

DATA SOURCES 15

RESULTS 17

Abiotic influences 17
Biotic influences 29

Growth Regimes 62
Length-weight relationships 62
Annual estimates of growth rates 69
Maturity Regimes 88
Abrasov's estimate of the mean age of maturity 88
Annual descriptions of maturity regimes 89
Relationships of maturity and growth regimes 94
Survival Regimes 98
Annual survival estimates 98
Temporal changes in trawl catches of juvenile walleyes & saugers 109
Cohort Biomass 121
Fishery Influences 154
Recent Changes in Management Regulations 160
Recent Trends in Commercial Fishery Yields 179

DISCUSSION 196
Historical Development of the Lake Winnipeg Fish Stock Assessment and Management Programs 196
Paralimnological Effects on Cohort Strengths 199
Fishery Effects on Cohort Strengths 202
Required Refinements & Additional Work 205

REFERENCES 207

APPENDICES 217

LIST OF TABLES

Table | Page
1 Morphometry of Lake Winnipeg (from Brunskill et al. 1980) 18
2 Biomass and production estimates of major trophic components in Lake Winnipeg 30
3 Age-specific numbers, frequencies, mean lengths and mean weights of experimentally caught walleyes from the three major areas of Lake Winnipeg, 1976-83 33
4 Age-specific numbers, frequencies, mean lengths and mean weights of experimentally caught saugers from the three major areas of Lake Winnipeg, 1976-83 39
5 Age-specific numbers, frequencies, mean lengths and mean weights of experimentally caught whitefish from the three major areas of Lake Winnipeg, 1972-83 47
6 Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from Lake Winnipeg, 1979 55
7 Age compositions and mean lengths and weights of commercial catches in northern and southern Lake Winnipeg, 1980. Numbers in parentheses are percentage frequencies 57

LIST OF TABLES

Table Page

8 Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from Lake Winnipeg, 1981. Numbers in parentheses are frequencies (%) 58

9 Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from the three major areas of Lake Winnipeg, 1982. Numbers in parentheses are percentages 59

10 Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from Lake Winnipeg, 1983. Numbers in parentheses are percent frequencies 61

11 Geometric mean functional length-weight relationships[a] of walleyes, saugers and whitefish from Lake Winnipeg, 1979-83 70

12 Exponential and von Bertalanffy growth curves of whitefish, walleyes and saugers from Lake Winnipeg, 1972-83 72

13 Walford plots of walleyes, saugers and whitefish from the major areas of Lake Winnipeg, 1979-83 74

LIST OF TABLES

Table		Page
14	Relationships of $\log_e$ $(L_\infty - l_t)$ and t (years) for whitefish, walleye and sauger stocks from Lake Winnipeg, 1972-83	76
15	Maturity curves of female walleyes, saugers and whitefish from major areas of Lake Winnipeg, 1979-83	90
16	Temporal regressions of maturity rates and $\bar{A}_m$.	92
17	Relationships of instantaneous maturity rates and the growth parameters of Lake Winnipeg stocks	97
18	Annual survival rates of walleye, sauger and whitefish stocks from the three major areas of Lake Winnipeg	107
19	Mean numbers of young walleyes and saugers caught per trawl in three areas of Lake Winnipeg, 1976-83 .	110
20	Vernal warming rates of Lake Winnipeg surface water recorded at Gimli, 1972-1982	112
21	Observed and predicted walleye and sauger CUE values and values of independent variables	122

LIST OF TABLES

Table Page

22 Maturity regimes, commercial fishery effects and estimates of biomass per 1000 newborn fish for south basin walleye cohorts. Mean individual body weight=$\bar{w}$(kg.), number of fish=N, biomass, B=$\bar{w}$.N, frequency of mature females =% matF., frequency of fish in commercial catches = % comm. Dashes denote pre and post 1979 ageing discrepancy 123

23 Maturity regimes, commercial fishery effects and estimates of biomass per 1000 newborn fish for north bsin walleye cohorts. Mean individual body weight= $\bar{w}$(kg), number of fish=N, biomass, B=$\bar{w}$.N, frequency of mature females =% matF., frequency of fish in commercial catches =% comm 128

24 Maturity regimes, commercial fishery effects and estimates of biomass per 1000 newborn fish for south basin sauger cohorts. Mean individual body weight= $\bar{w}$(kg.), number of fish=N, biomass, B=$\bar{w}$.N, frequency of mature females=%matF., frequency of fish in commercial catches =% comm. Dashes denote pre and post 1979 ageing discrepancy 132

LIST OF TABLES

Table | Page

25 Maturity regimes, commercial fishery effects and estimates of biomass (kg) per 1000 newborn fish for north basin sauger cohorts. Mean individual body weight = $\bar{w}$(kg), number of fish=N, biomass, B=$\bar{w}$.N, frequency of mature females = %matF, frequency of fish in commercial catches = % comm ... 137

26 Maturity regimes, commercial fishery effects and estimates of biomass (kg) per 1000 newborn fish for north basin whitefish cohorts. Mean individual body weight = $\bar{w}$ (kg), number of fish = N, biomass, B = $\bar{w}$.N, frequency of mature females = %matF, frequency of fish in commercial catches = %comm. Dashes denote pre and post 1979 ageing frequency ... 141

27 Annual estimates of sex ratios (male:female) of walleye, sauger and whitefish stocks 145

28 Annual estimates of spawning female biomass removed by the fishery and escaping the fishery in Lake Winnipeg. Figures in parentheses are removal rates (%) 150

29 Concomitant effects of changes in the fishery and environment on observed trawl catches of yoy walleyes and saugers from the south basin of Lake Winnipeg .. 151

LIST OF TABLES

Table Page

30 Historical yields and landed values of the Lake Winnpeg commercial fisheries, 1931-83 155

31 Historical yields densities and landed value densities of the Lake Winnipeg commercial fisheries, 1931-83 161

32 Regulatory changes in the summer fishery of the Lake Winnipeg management areas, 1970-81 165

33 Regulatory changes in the autumnal fishery of the Lake Winnipeg management areas, 1970-83 169

34 Regulatory changes in the winter fishery of the Lake Winnipeg mangement areas, 1970-83 171

35 Changes in surface areas (hectares) of Lake Winnipeg's management zones from 1971-1983 174

36 Numbers of fish fry stocked annually in Lake Winnipeg, 1970-83 177

37 Commercial catches (kg), fishing effort (no. deliveries and CUE (kg delivery^{-1}) for walleyes, saugers and whitefish from the three major regions of Lake Winnipeg, 1972-83 182

38 Lake Winnipeg's commercial catches reported by Manitoba Fisheries Branch and effort (no. deliveries) reported by FFMC 186

LIST OF TABLES

Table		Page
39	Annual, whole lake quotas and commercial catches of quota species (walleyes, saugers and whitefish)..	187
40	Annual surface densities of walleye and sauger yields and quotas of Lake Winnipeg's south basin management zone	188

LIST OF FIGURES

Figure Page

1 Bathymetric map of Lake Winnipeg (from Brunskill *et al*. 1980) 2

2 Effects of incurrent rivers on distributions of silt, sand and clay in Lake Winnipeg (from Brunskill and Graham 1979) 19

3 The relationship between annual river discharge (Q_a) and annual suspended sediment transport (SS) for the Red, Winnipeg, and Saskatchewan Rivers over 1965 to 1976 (from Brunskill *et al*. 1980) 20

4 Vertical extinction coefficient of light as a function of suspended sediment concentration in Lake Winnipeg waters (from Brunskill *et al*. 1979) .. 22

5 Spectral extinction of light in Lake Winnipeg waters measured in the north basin (A), channel (B) and south basin (C) (from Brunskill *et al*. 1979). 23

6 The relationship between annual river discharge and annual nitrogen transport rate to Lake Winnipeg (from Brunskill *et al*. 1980). 24

7 The relationship between annual river discharge and annual phosphorus transport rate to Lake Winnipeg (from Brunskill *et al*. 1980) 25

Figure Page

8 Historical and extrapolated trends in the annual release of nitrogen to the land and water of the Lake Winnipeg sedimentary drainage area (from Brunskill _et_ _al_. 1980) 26

9 Historical and extrapolated trends in the annual release of phosphorus to the land and water of the Lake Winnipeg sedimentary drainage area (from Brunskill _et_ _al_. 1980).............................. 27

10 Spring, summer and fall thermal plumes induced by rivers entering Lake Winnipeg (from Brunskill _et_ _al_. 1979) 28

11 Age specific mean lengths of south basin walleyes .. 63

12 Age specific mean lengths of north basin walleyes .. 64

13 Age specific mean lengths of south basin walleyes .. 65

14 Age specific mean lengths of north basin walleyes .. 66

15 Age specific mean lengths of north basin walleyes .. 67

16 Age specific mean lengths of channel whitefish 68

17 Concomitant temporal changes in estimates of L_∞ and K values for northern (n) and southern (s) Lake Winnipeg walleye stocks 78

Figure Page

18 Concomitant temporal changes in estimates of L_∞ and K values for the northern Lake Winnipeg whitefish stock 79

19 Concomitant temporal changes in estimates of L_∞ and K values of northern (A) and southern (B) Lake Winnipeg sauger stocks 80

20 Temporal changes in the Pauly statistic of northern and channel Lake Winnipeg whitefish stocks 81

21 Temporal changes in the Pauly statistic of northern and southern Lake Winnipeg walleye stocks 82

22 Temporal changes in the Pauly statistic of northern, channel and southern Lake Winnipeg sauger stocks ... 83

23 Temporal changes in exponential growth rates of northrn and channel Lake Winnipeg whitefish stocks . 85

24 Temporal changes in exponential growth rates of northern, channel and southern Lake Winnipeg sauger stocks 86

25 Temporal changes in exponential growth rates of northern and southern Lake Winnipeg walleye stocks . 87

26 Temporal changes in mean ages of maturity, $\overline{A}_m$ (▲) and instantaneous maturity rates (●) of the north basin whitfish stock 93

Figure Page

27 Temporal changes in mean ages of maturity ($\bar{A}_m$) and instantaneous maturity rates of north basin (▲) and south basin (●) sauger stocks. Circled datum was deleted from analysis 95

28 Temporal changes in mean ages of maturity ($\bar{A}_m$) and instantaneous maturity rates of north basin (▲) and south basin (●) walleye stocks. Circled datum was deleted from analysis 96

29 Relationships of instantaneous maturity rates to exponential growth rates, E, and Pauley statistics, P, of north basin (A) and south basin (B) sauger stocks. Circled points were omitted from regression analysis 99

30 Relationship of instantaneous maturity rate to: exponential growth rate, E, of south basin walleyes (A), Pauley statistic, P, of south basin walleyes (B) and exponential growth rate of north basin walleyes (C) 100

31 Relationship of instantaneous maturity rate the Pauley statistic, P, and exponential growth rate of north basin whitefish 101

Figure Page

32 Annual north basin walleye age compositions determined by experimental gillnetting 102

33 Annual south basin walleye age compositions determined by experimental gillnetting 103

34 Annual north basin sauger age compositions determined by experimental gillnetting 104

35 Annual south basin sauger age compositions determined by experimental gillnetting 105

36 Annual north basin whitefish age compositions determined by experimental gillnetting 106

37 Observed and predicted CUE (mean no. fish trawl^{-1}) values for south basin walleyes 114

38 Observed and predicted CUE (mean no. fish trawl^{-1}) values for south channel walleyes 115

39 Observed and predicted CUE (mean no. fish trawl^{-1}) values for pooled channel walleyes 116

40 Observed and predictec CUE (mean no. fish trawl^{-1}) values for south basin walleyes 117

41 Observed and predicted CUE (mean no. fish trawl^{-1}) values for southern channel saugers 118

42 Observed and predicted CUE (mean no. fish trawl^{-1}) values for pooled channel saugers 119

Figure		Page
43	Cohort biomass curves of south basin walleyes	146
44	Cohort biomass curves of south basin walleyes	147
45	Cohort biomass curves of north basin walleyes	148
46	Total and species specific commercial catches (annual marketed weight) from Lake Winnipeg, 1931-70	159
47	Spatial and temporal distributions of walleye, sauger and whitefish CUE (kg delivery $^{-1}$) values from Lake Winnipeg's commercial fisheries	178
48	Spatial and temporal distribution of fishing effort (no. deliveries x 10^4) on Lake Winnipeg	180
49	Spatial and temporal distribution of walleye, sauger and whitefish commercial catches (kg x 10^6) from Lake Winnipeg	181
50	Relationship of fishing effort and commercial catches of walleyes (▲), whitefish (○), saugers (●), non quota species (□) and all species (■) from Lake Winnipeg. Circled points were deleted from fitting of the parabola	184
51	Compensatory responses in growth (W = mean individual body weight) of walleye age groups in southern and northern Lake Winnipeg	193

Figure Page

52 Compensatory responses in growth (W = mean individual body weight) of sauger age groups in northern and southern Lake Winnipeg 194

53 Lack of compensatory responses in growth (W = mean individual body weight) of whitefish age groups in northern Lake Winnipeg 195

LIST OF APPENDICES

Appendix | Page

A Multiple regressions of walleye and sauger CUE values as functions of warming rates and flow rates of Lake Winnipeg's incurrent rivers 217

B Quota Species Values 225

C Models predicting abundances of yoy walleyes and saugers as functions of water warming rates, flow rates of incurrent rivers and biomasses of mature female walleyes and saugers escaping Lake Winnipeg's commercial fisheries 227

INTRODUCTION

Lake Winnipeg is the thirteenth largest lake in the world and the seventh largest lake on the North American continent. Lake Winnipeg is 436 km. long and 111 km. wide. The lake is composed of three morphologically distinct areas: the north basin, channel and south basin. Mean depths of these three areas are 13.3m., 7.2m. and 9.7m., respectively (Fig. 1) (Brunskill et al. 1980). Vertical stratification of temperature and oxygen concentration does not occur during the ice free season since the lake is relatively shallow and exposed to strong winds. Horizontal gradients for most limnological parameters are partly controlled by the orientation of main rivers and basin morphology (Brunskill et al. 1979).

Precambrian shield rivers on the eastern shores of Lake Winnipeg have high discharge rates but carry low concentrations of nutrients, salts and sediments derived from igneous rock and acidic soils. These rivers provide over 50% of the lake's annual water supply. Rivers entering Lake Winnipeg along the southwestern shores carry higher concentrations of nutrients, salts and sediments but have lower discharge rates. These rivers drain agricultural and urban areas of sedimentary rock overlain by Lake Agassiz sediments. Brunskill et al. (1980) estimated that in 1969, 9000 tonnes of phosphorus and 100,000 tonnes of nitrogen entered

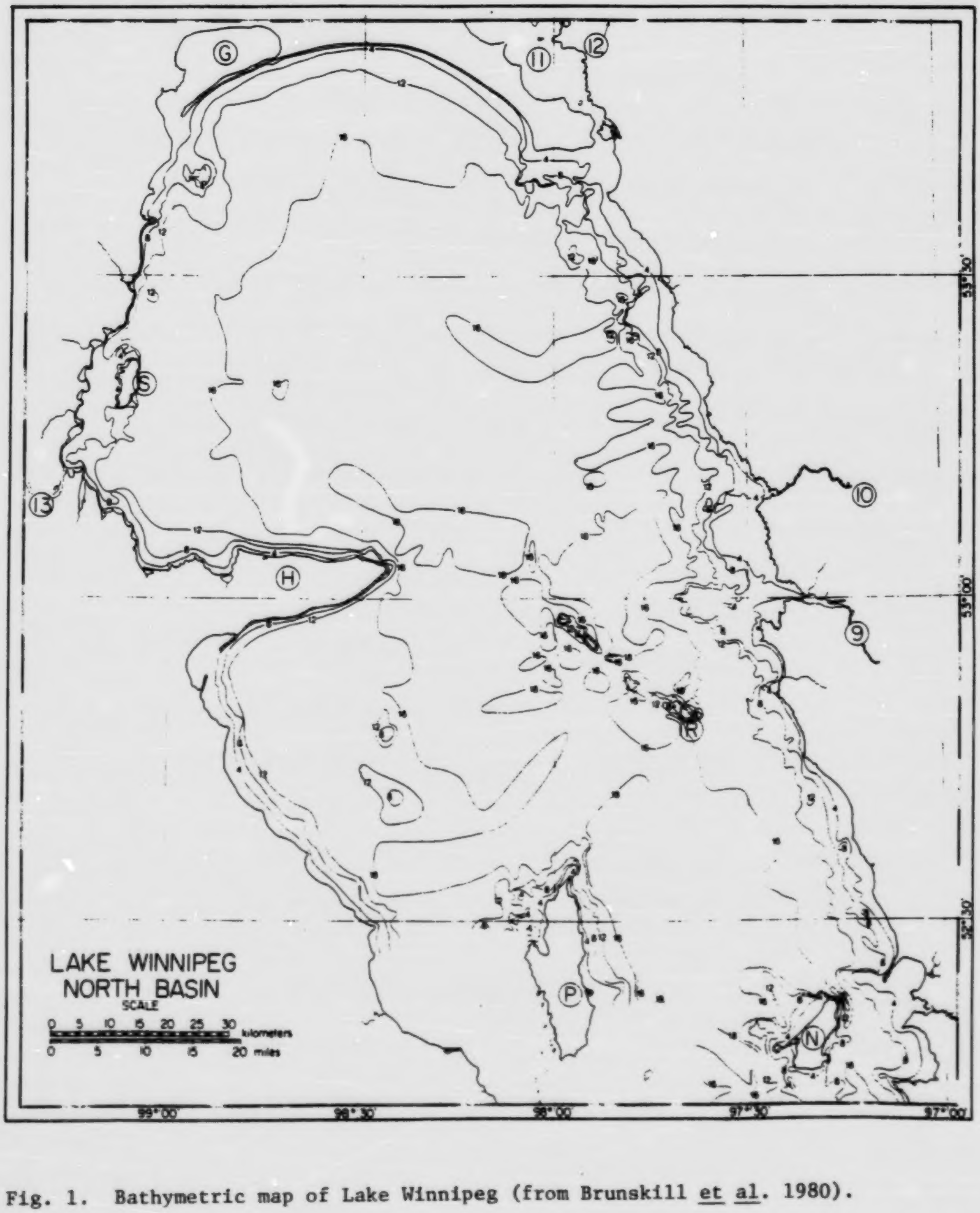
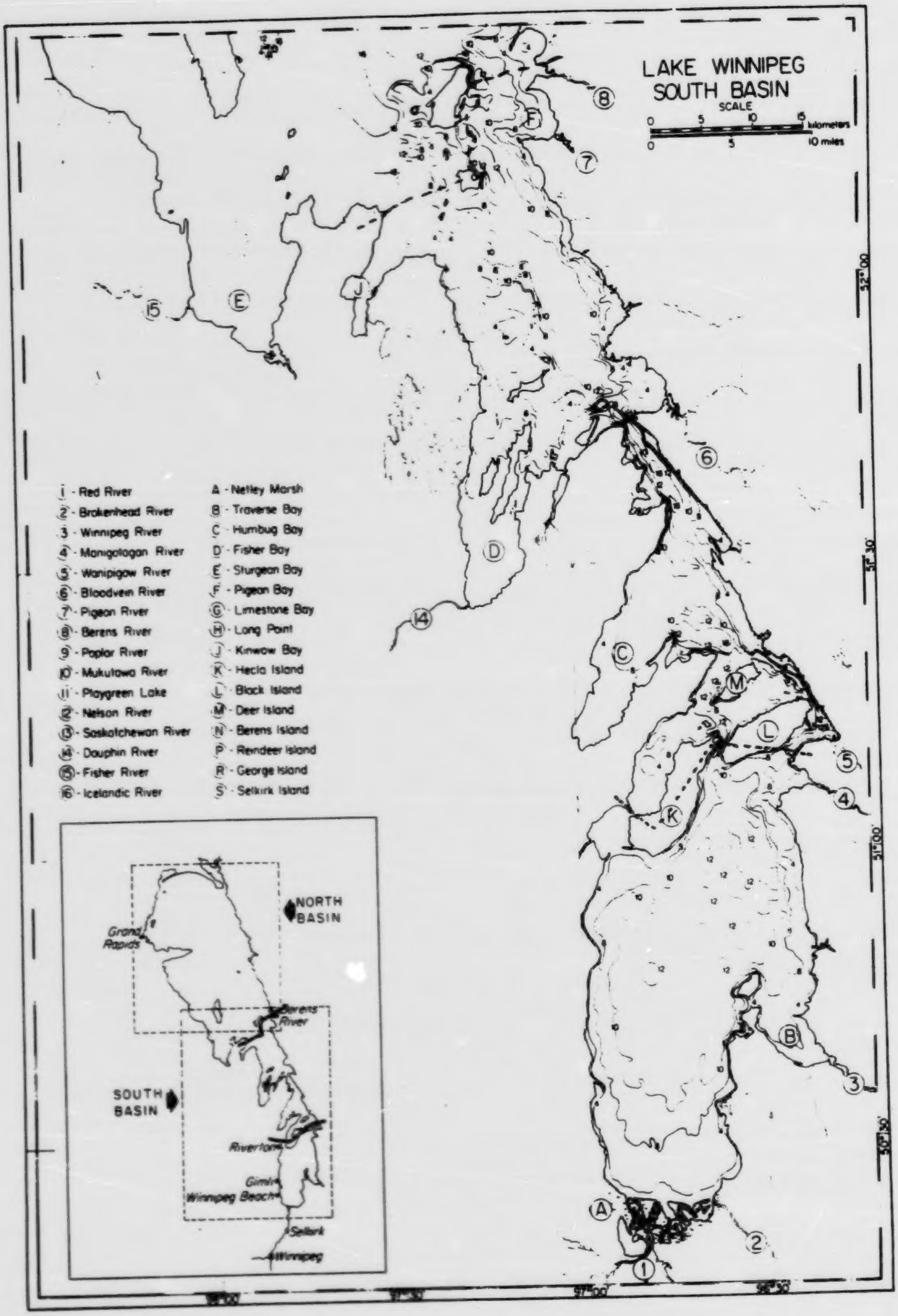

LAKE WINNIPEG
NORTH BASIN
SCALE
0 5 10 15 20 25 30 kilometers
0 5 10 15 20 miles
G
H
S
R
P
N
9
10
11
12
13
99°00'
98°30'
98°00'
97°30'
97°00'
53°30'
53°00'
52°30'

Fig. 1. Bathymetric map of Lake Winnipeg (from Brunskill *et al*. 1980).


LAKE WINNIPEG
SOUTH BASIN
SCALE
0 5 10 15 kilometers
0 5 10 miles
1 - Red River
2 - Brokenhead River
3 - Winnipeg River
4 - Manigotagan River
5 - Wanipigow River
6 - Bloodvein River
7 - Pigeon River
8 - Berens River
9 - Poplar River
10 - Mukutawa River
11 - Playgreen Lake
12 - Nelson River
13 - Saskatchewan River
14 - Dauphin River
15 - Fisher River
16 - Icelandic River
A - Netley Marsh
B - Traverse Bay
C - Humbug Bay
D - Fisher Bay
E - Sturgeon Bay
F - Pigeon Bay
G - Limestone Bay
H - Long Point
J - Kinwow Bay
K - Hecla Island
L - Black Island
M - Deer Island
N - Berens Island
P - Reindeer Island
R - George Island
S - Selkirk Island
NORTH BASIN
SOUTH BASIN
Grand Rapids
Berens River
Riverton
Gimli
Winnipeg Beach
Selkirk
Winnipeg
52°00'
51°30'
51°00'
50°30'
98°00'
97°30'
97°00'
96°30'

the lake, primarily through the Red River.

Primary production in Lake Winnipeg seems to be limited by turbidity rather than nutrients. The construction of several hydro-electric generating stations on the Saskatchewan River since the turn of the century has decreased turbidity and nutrient loading in the north basin.

Horizontal distributions of the silt, sand and clay are also partly related to the orientation of major rivers (Brunskill and Graham 1979). The distributions of sediment types in turn partly affect distributions of macrobenthic species. The amphipod, *Pontoporeia hoyi*, and two mayflies, *Hexagenia limbata* and *Hexagenia rigida*, along with a host of chironmids and oligochaetes are the major components of Lake Winnipeg's macrobenthos (Flannigan 1981,Saether pers. comm.). *P. hoyi* has disappeared from Lake Winnipeg's southern basin since 1930. This is probably due to chemical pollution from the Red River. Densities of *H. limbata* have declined in the south basin and channel but have increased in the north basin. Two caddisfly species have also disappeared from the southern basin (Flannigan and Cobb 1981).

Thirty four species of zooplankters inhabit Lake Winnipeg. *Cyclops bicuspidatus*, *Cyclops vernalis* and *Diaptomus ashlandi* comprise 80% of the numbers of crustaceans. The mean zooplankton volume in Lake Winnipeg has doubled since 1930 due to to increased nutrient loading (Patalas 1981).

Lake Winnipeg stocks of walleyes, Stizostedion vitreum, saugers, Stizostedion canadense, and whitefish, Coregonus clupeaformis, have been exploited by commercial fishermen since the latter part of the nineteenth century. Annual yields of these species increased until the 1950's and declined irregularly from 1950-1970 when the fishery was closed due to mercury contamination. This respite from fishing pressure and optimal spawning conditions allowed the development of strong cohorts. Annual yields increased rapidly during the early 1970's. Recently, Lake Winnipeg has been producing 41% of the entire commercial catch in Manitoban waters and 10% of the entire Canadian freshwater catch (Gislason et al. 1982). Walleyes, saugers and whitefish comprise the majority of Lake Winnipeg catches that are controlled by quota, season, area and mesh size regulations. Recent annual yields of these three species are about 4.8 million kg.

The major whitefish fishery on Lake Winnipeg occurs on the northern basin of the lake during June. The sauger and walleye fisheries occur primarily on the south basin and channel and in isolated areas along the northeastern and northwestern shores. Saugers and walleyes are harvested during the summer and fall seasons and to a lesser extent in winter. Lake Winnipeg fisheries have been decribed in detail by Kennedy (1954), Doan (1959), Hewson (1959, 1960) and Davidoff et al. (1973).

Lake Winnipeg fishery management regulations are recorded annually in the Manitoba Gazette (Province of Manitoba).

Many research projects dealing with diverse topics have been conducted on Lake Winnipeg since 1930. Early reports were generalized descriptions of fisheries (Bajkov 1930, Grant 1938, Hewson 1951), fish parasites (Bajkov 1933, Kennedy 1951, Keleher 1952), plankton (Bajkov 1934), benthos (Neave, 1932, 1933, 1934; Arnason 1951) and species compositions and distributions (Hinks 1943, Keleher and Kooyman 1957). Later reports dealt routinely with the status of exploited fish stocks (Kooyman 1952, Doan 1959, Hewson 1959, 1960; Rybicki and Doan 1966), mesh size effects (Kooyman 1955, Hewson 1957) and mark-recapture experiments (Hewson 1953, Kennedy 1954, Rybicki 1961, 1962). Recently, more specialized reports have dealt with mercury and pesticide pollution(Bligh 1970, 1972; Kennedy 1972, Reinke et al. 1972, Scott and Armstrong 1972), limnology (Kushner 1971, Evans and Stockner 1972, Kristofferson et al. 1975, Brunskill et al. 1980) and advances in ecological monitoring (Green 1971, 1972).

A review of former studies of Lake Winnipeg's exploited fish stocks presents a diverse array of different approaches and techniques of sampling and analyses (Kennedy 1954, Hewson 1959, 1960; Davidoff et al. 1973, Howard 1974). This methodological diversity confounds comparisons of results when one attempts to analyse long term changes in the dynamics of Lake Winnipeg's fish stocks.

In 1979, a standardized, annual fish stock assessment program was initiated on Lake Winnipeg in an attempt to minimize incongruities created by changing methodology. The annual objectives of this program were to:

1. describe growth and maturity regimes of Lake Winnipeg walleye, sauger and whitefish stocks
2. estimate mortality rates
3. compare mean biomasses of fish net^{-1} $night^{-1}$ caught in various mesh sizes set in the three major areas of the lake
4. determine age and size characteristics of commercial catches.

Data sets and analyses from the annual stock assessment programs were presented by Lysack (1980, 1981, 1982, 1983, 1984).

The objectives of this report are to:

1. describe spatial and temporal gradients of three groups of influences that may potentially affect commercial fishery yields. Important factors comprising the ABIOTIC group are lake morphometry, thermal regimes, flow and nutrient regimes of

incurrent rivers and light attentuation. The BIOTIC group consists of primary production and secondary (zooplanktonic and benthic) production. The FISHERY group includes spatial and temporal gradients in numbers of fishermen, daily yardage allowances, season lengths, quotas and mesh sizes.

2. describe recent compensatory changes in growth and maturity regimes of commercially exploited stocks.
3. examine the predictive utility of some of the above variables with respect to year class strengths of walleyes and saugers.

METHODS AND MATERIALS

Since 1979, the two major components of the annual stock assessment program on Lake Winnipeg have been experimental netting and commercial sampling (Lysack 1980, 1981, 1982, 1983, 1984).

Experimental netting

Experimental gangs of gillnets were set at 24 - 33 stations during each summer from 1979-1983. One or two gangs of gillnets were set at each station for one overnight period (16-18 hours). Gangs set in the south basin and southern reaches of the channel were composed of the following meshes: 7.62 cm (3 in), 8.26 cm (3.25 in), 8.89 cm (3.5 in), 9.53 cm (3.75 in), 10.16 cm (4 in) and 10.80 cm (4.25 in). A 12.70 cm (5 in) net and a 13.34 cm (5.25 in) net were added to the above gang for sets made in the northern reaches of the channel and in the north basin. Each net in the gang was 90 m (100 yards) long and approximately 1.83 m (2 yards) deep.

Walleyes, saugers and whitefish caught in each gang were processed as follows: The fork length of each fish was measured to the nearest 2 mm. In 1979, each fish was weighed to the nearest 20 gm on a Chatillon spring scale (Chatillon, Mississauga, Ontario) A more accurate (± 5 gm) scale was used from 1980-1983. Six to ten scales were collected from the left side of each fish. Scales were removed above the lateral line below the anterior edge of the dorsal fin. The sex and state of maturity of each fish was visually determined by examining gonads. The mesh size that caught each walleye, sauger and whitefish was recorded. A microfiche reader (Data View, model LF1015) was used to analyse scales at 24X and 48X.

Commercial sampling

Commercial catches were sampled during the summer and fall commercial fishing seasons. Samples were collected from fishermen's catches at Warren Landing, Grand Rapids, Gull Bay, Sturgeon Bay, George Island, Big Black River, Berens River, Matheson Island, Gimli and Selkirk. Walleyes, saugers and whitefish were randomly selected from catches and were processed in the same manner as experimentally caught fish. Sex and state of maturity of commercially caught fish were not determined.

Calculations

Routine statistical analyses were performed according to Snedecor and Cochran (1967). Total mortality rates, Z, were calculated according to Robson and Chapman (1961). In certain cases, when the number of age classes on the descending limb of the catch curve was too small to allow calculation of Z, the peak value of the age distribution and/or age classes containing fewer than five fish were used. A regression analysis of the descending limb of the catch curve was used to provide another estimate of Z. Log transformed age-specific frequencies, not numbers, were used to construct catch curves.

Length-weight relationships for experimentally netted walleyes, saugers and whitefish were derived by least squares regression analyses of age-specific mean lengths and mean weights. Walford lines and Brody-Bertalanffy equations were derived according to Ricker (1975). In some of the annual Lake Winnipeg stock assessment reports, t_o values used in fitting von Bertalanffy growth curves were miscalculated. These errors were corrected according to:

$$t_o = \frac{\text{Brody y axis intercept} - \text{Log}_e L_\infty}{K}$$

and the corrected versions of the von Bertalanffy growth curves are presented in this report.

Temporal changes in frequencies of mature fish were described using a logistical model:

$$Y_x = \frac{k}{1+e^{-b(x-x_o)}}$$

where Y_x = frequency of mature fish among all fish aged x

k = frequency of mature fish among the oldest age groups

X_o = age at inflection point

b = slope

It was assumed that k = 100%. To facilitate fitting a linear regression, data were transformed by:

$$\log_e\left(\frac{k-y}{y}\right) = -bX_o+bX$$

Values of y approaching 0 or 1 were deleted.

The mean biomass net^{-1} night^{-1} of walleyes, saugers and whitefish caught in each major area of Lake Winnipeg was calculated by:

$$\overline{B} = \frac{\Sigma w}{n}$$

where $\overline{B}$ = species-specific mean biomass net^{-1} night^{-1}

w = sum of all the individual weights of fish of a species caught in a specific mesh in all gangs set in a major lake area

n = number of gangs set in an area.

In cases where all fish caught in a gang were not sampled, the number of unsampled fish was added to the number of sampled fish and this sum was multiplied by the mean individual weight of fish caught in a specific mesh to estimate Σw.

Annual experimental data and annual commercial catch data were pooled according to 3 major areas of the lake. These 3 major areas roughly approximate zones of differing legal minimum commercial mesh sizes. Thus the south basin data pool was collected from a 3 inch mesh size zone, the channel data pool was collected from a 3.75 inch mesh size zone and the north basin data pool was collected from a 4.25-5.00 inch mesh size zone. In some years, sample sizes of certain species in certain management zones (usually the channel area) were too small to determine patterns of growth, maturity, mortality, etc.

Concurrent studies

In 1980, lipid content and growth characteristics of Lake Winnipeg whitefish stocks were examined to determine the cause of the decline in quality of commercial catches of whitefish in recent years (O'Connor 1981).

Olynyk (1982) determined the number of eggs produced by southern Lake Winnipeg walleyes as a function of body size and compared this relationship to a 1975 counterpart to see if fecundity had changed.

A trawling program is currently being conducted in the south basin and channel of Lake Winnipeg to determine relationships between pre-recruited and recruited walleyes and saugers (Kristofferson 1985).

DATA SOURCES

All of the abiotic data on lake basin morphometry, sediments, nutrient loading, etc. were obtained from a series of technical reports written by Brunskill *et al.* (see "references"). Data on flow rates of major rivers entering Lake Winnipeg were obtained from a continuing series of data reports published by Environment Canada, Water Resources Branch.

Estimates of the biomass and productivity of phytoplankton, zooplankton and major benthic invertebrates were obtained from unpublished data collected by several workers from the Freshwater Institute, Winnipeg and from Flannigan (1981).

Historical commercial fishery yield data (1931-1968) were found in the data files of the Fisheries Branch, Manitoba Dept. of Natural Resources, Winnipeg. Recent commercial fishery yield data (1969-1983) were provided by the Freshwater Fish Marketing Corporation, Winnipeg. Private fish marketing companies recorded the commercial yields from Lake Winnipeg until 1969. From 1931 to 1975, yields were recorded in terms of dressed or marketed weights. In 1976, the Freshwater Fish Marketing Corporation began recording marketed catches in terms of round weight. To standardize the annual yields from 1931 to 1983 listed in this report, conversion factors for each species marketed during 1978-81 were used to convert round weights to dressed weights (R. Peters, Man. Dept. of Natural Resources, pers. com.)

Annual stock assessment data collected from commercial catch samples and annual gillnetting programs (1972-83) were provided by regional fisheries personnel, Man. Dept. of Natural Resources.

Recent management regulations (1972-83) were obtained from the Manitoba Gazette. Records of numbers of fishermen were provided by the Commercial Fishery Management Unit, Man. Dept. of Natural Resources.

RESULTS

Abiotic influences

The south basin of Lake Winnipeg is relatively smaller (in terms of surface area and volume) and shallower than the channel and north basin. The channel is a constricted zone with a highly irregular shoreline. It forms a passage between the northern and southern basins for movements of water and fish stocks (Table 1).

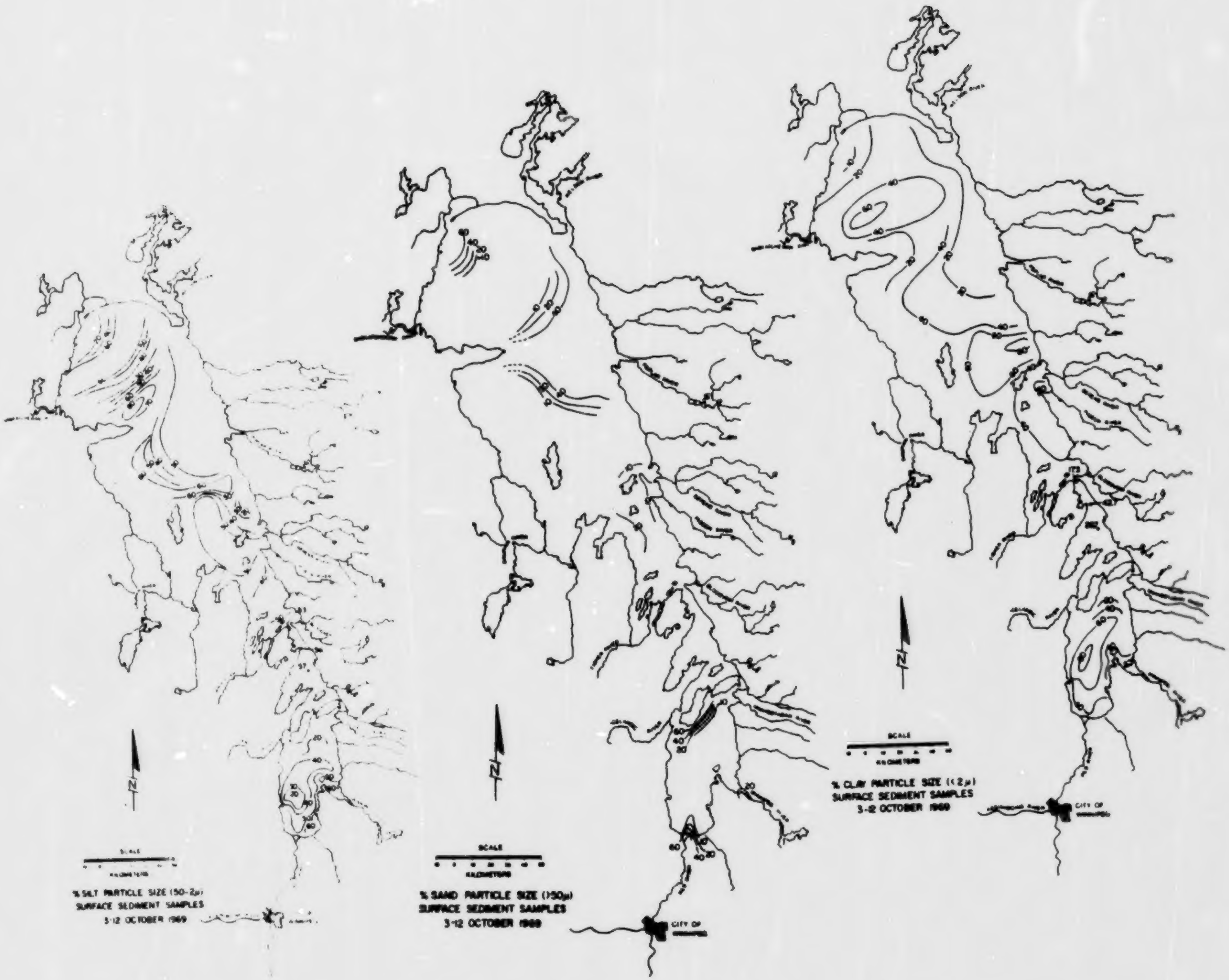
Plumes of major incurrent rivers affect the distribution of sand, silt and clay (Fig. 2). Annual sediment loads entering the lake via major rivers are primarily a function of annual river discharges (Fig. 3). The Red and Assiniboine rivers contribute a major fraction of the sediment while eastern rivers draining the Precambrian shield contribute the smallest amounts of sediment. A hydro-electric dam at the mouth of the Saskatchewan River (Grand Rapids) prevents that river from discharging its sediment load into Lake Winnipeg. Cedar Lake acts as a settling basin for these sediments.

Suspended sediment concentrations are related to the vertical light extinction coefficient according to:

Table 1. Morphometry of Lake Winnipeg (from Brunskill *et al*. 1980).

Measurement	Lake region*			Total lake
	North basin	Channel	South basin	
Surface area(km^2)	17,520	3,450	2,780	23,750
Volume (km^3)	232.4	24.6	27.0	284
Mean depth(m)	13.3	7.2	9.7	12.0
Maximum depth(m)	19	36	14	36
Maximum length(km)	232	143	93	436
Maximum breadth(km)	111	30	46	111
Shoreline length(km)	761	640	349	1,750
Shoreline development $(L/2\sqrt{\pi A_o})$	1.6	3.1	1.9	3.2
Volume development $(3\bar{z}/z_m)$	2.1	0.6	2.1	1.0
Relative depth $(50.z_{max}\sqrt{\pi}\ (\sqrt{A_{surface}})^{-1})$	0.013	0.054	0.024	0.021

*see Fig. 1. for boundaries.



% SILT PARTICLE SIZE (50-2μ)
SURFACE SEDIMENT SAMPLES
3-12 OCTOBER 1969

% SAND PARTICLE SIZE (>50μ)
SURFACE SEDIMENT SAMPLES
3-12 OCTOBER 1969

% CLAY PARTICLE SIZE (<2μ)
SURFACE SEDIMENT SAMPLES
3-12 OCTOBER 1969

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40
60
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Fig. 2. Effects of incurrent rivers on distributions of silt, sand and clay in Lake Winnipeg (from Brunskill and Graham 1979).

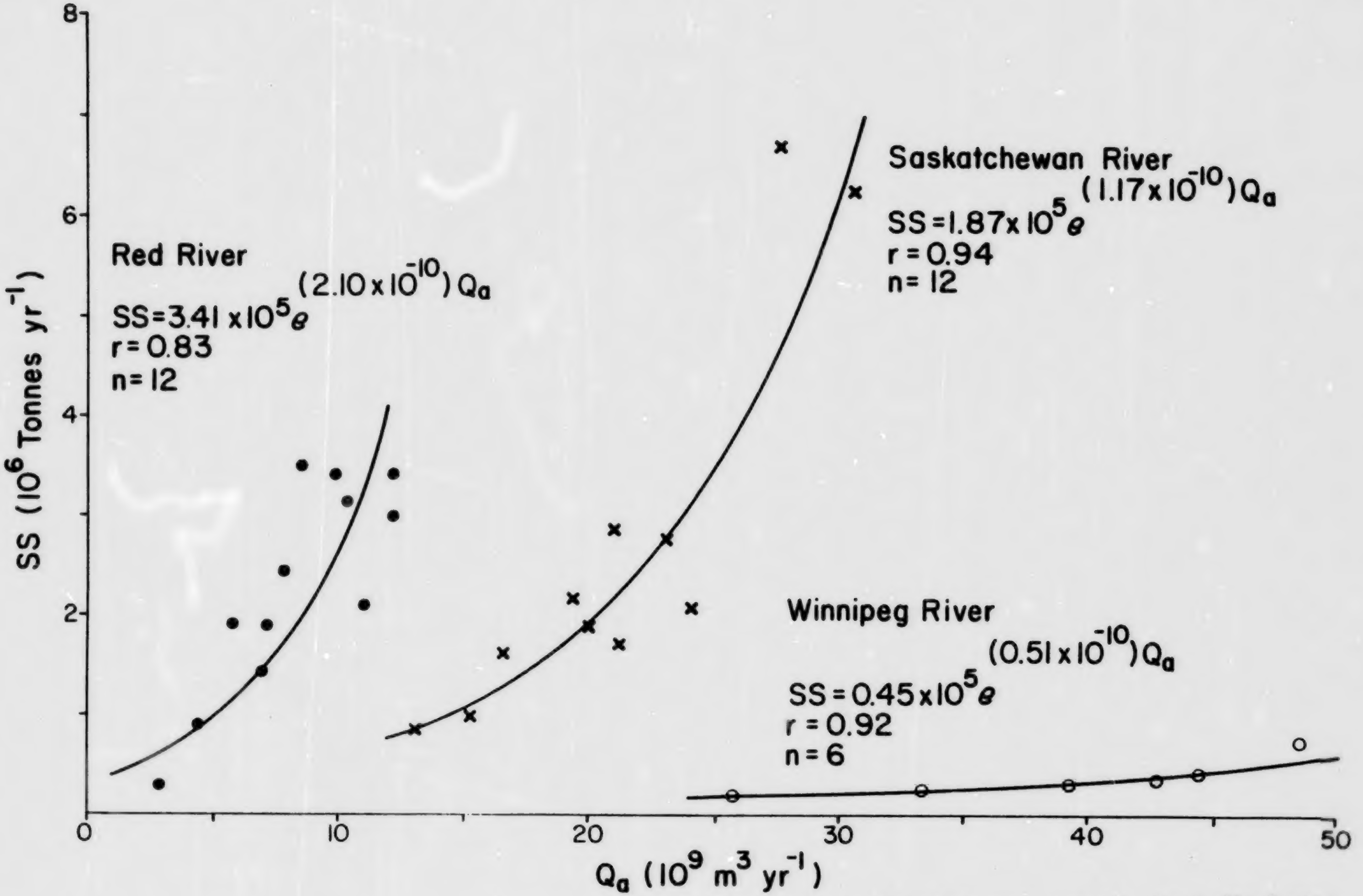


Fig. 3. The relationship between annual river discharge (Q_a) and annual suspended sediment transport (SS) for the Red, Winnipeg, and Saskatchewan Rivers over 1965 to 1976 (from Brunskill et al. 1980).

$$\log_e K_w(IS) = .5809-.1227\ SS$$

(Brunskill et al. 1979)

where $K_w(IS)$ = vertical extinction coefficient

SS = suspended sediment concentration (gm^{-3}) (Fig. 4)

Brunskill et al. (1979) found weaker relationships of algal biomass and light transmission through the water column. The more turbid waters of the south basin and channel quench blue and green light more than the clearer north basin waters (Fig. 5).

Inputs of the primary nutrients, nitrogen and phosphorus, vary annually as a function of river discharge (Figs. 6,7) and are increasing over longer terms (Figs. 8,9) as a function of fertilizer use, feedlot runoff and human waste runoff (Brunskill 1973, Brunskill et al. 1980).

Finally, incurrent rivers affect the thermal and chemical regimes of Lake Winnipeg. In spring, major rivers create large plumes of warm water. In the south basin, the Red River contributes 13-14°C water in June while in the north basin, the Berens, Pigeon and Saskatchewan Rivers provide 10°C water. As summer progresses, the river plumes' effect on water temperature become less pronounced. In autumn, the major rivers contribute water that is cooler than the lake water (Fig. 10).

Since Lake Winnipeg is shallow relative to its large surface area and has several large rivers contributing large volumes of water,

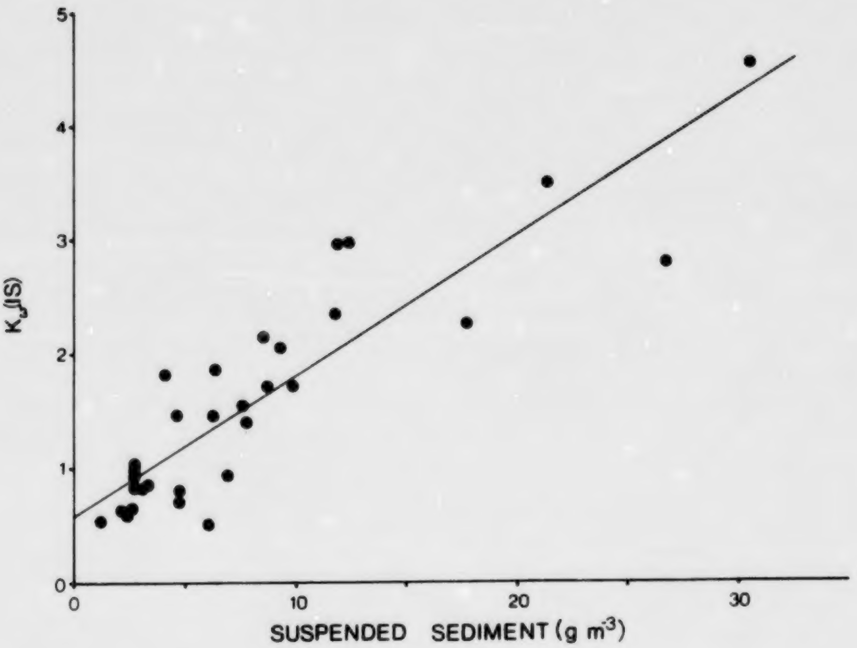


Fig. 4. Vertical extinction coefficient of light as a function of suspended sediment concentration in Lake Winnipeg waters (from Brunskill et al. 1979).

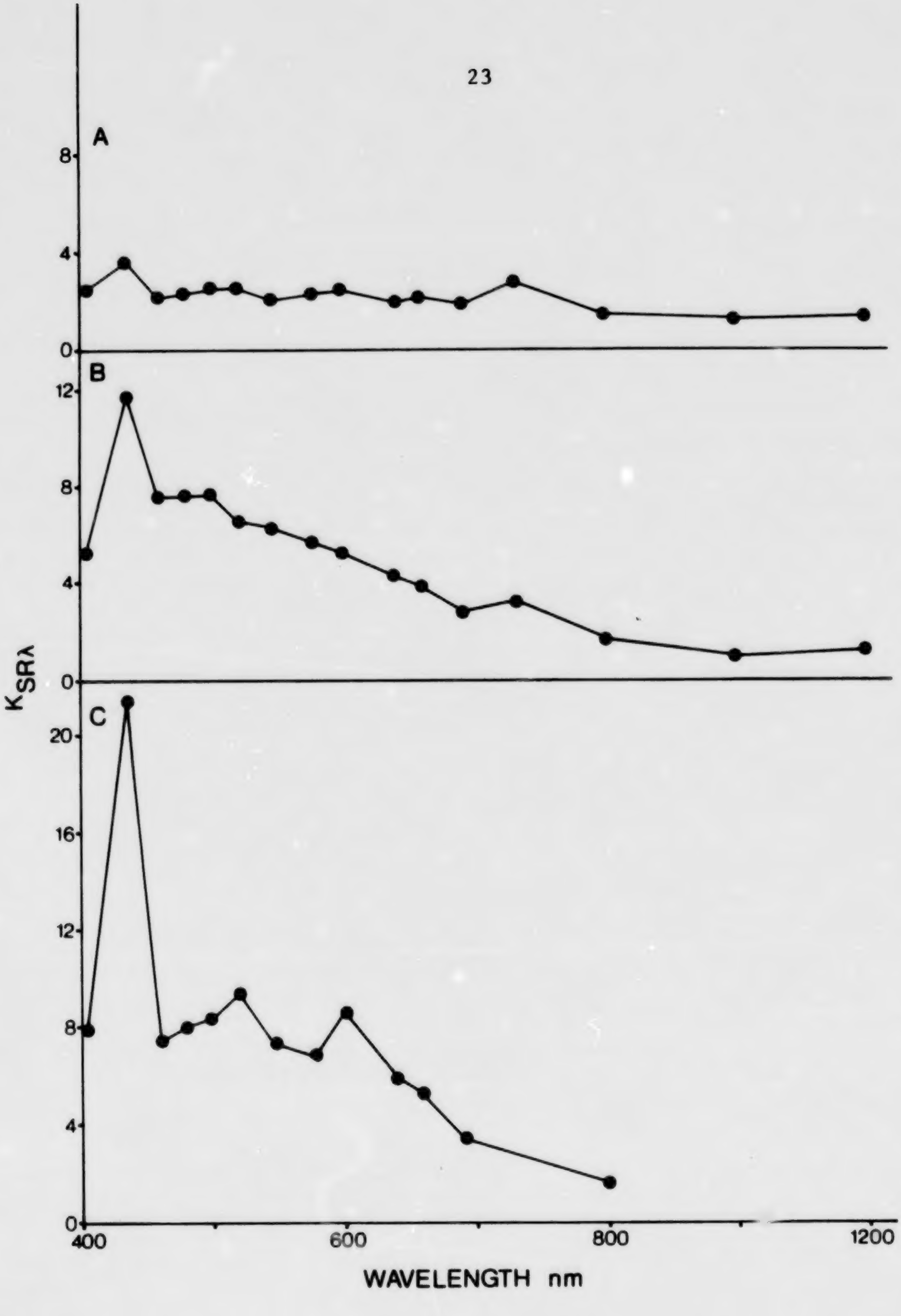


Fig. 5. Spectral extinction of light in Lake Winnipeg waters measured in the north basin (A), channel (B) and south basin (C) (from Brunskill *et al*. 1979).

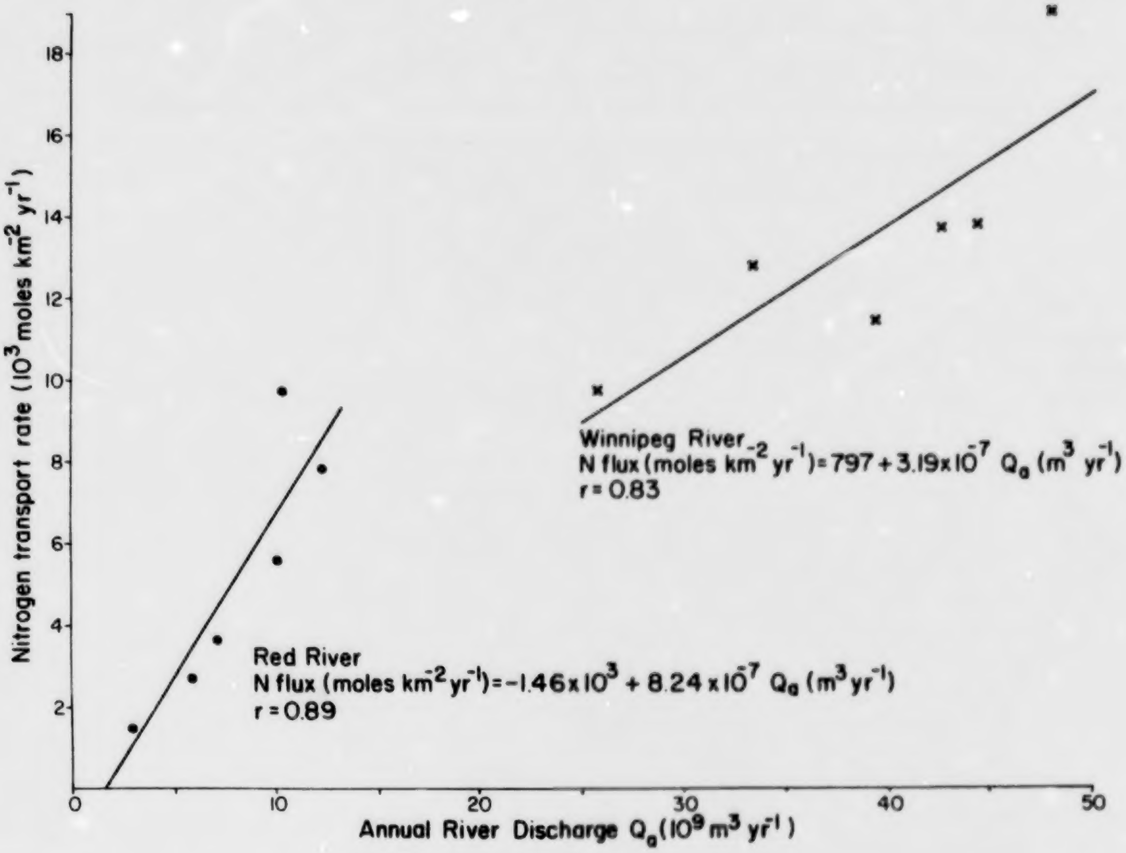


Fig. 6. The relationship between annual river discharge and annual nitrogen transport rate to Lake Winnipeg (from Brunskill et al. 1980).

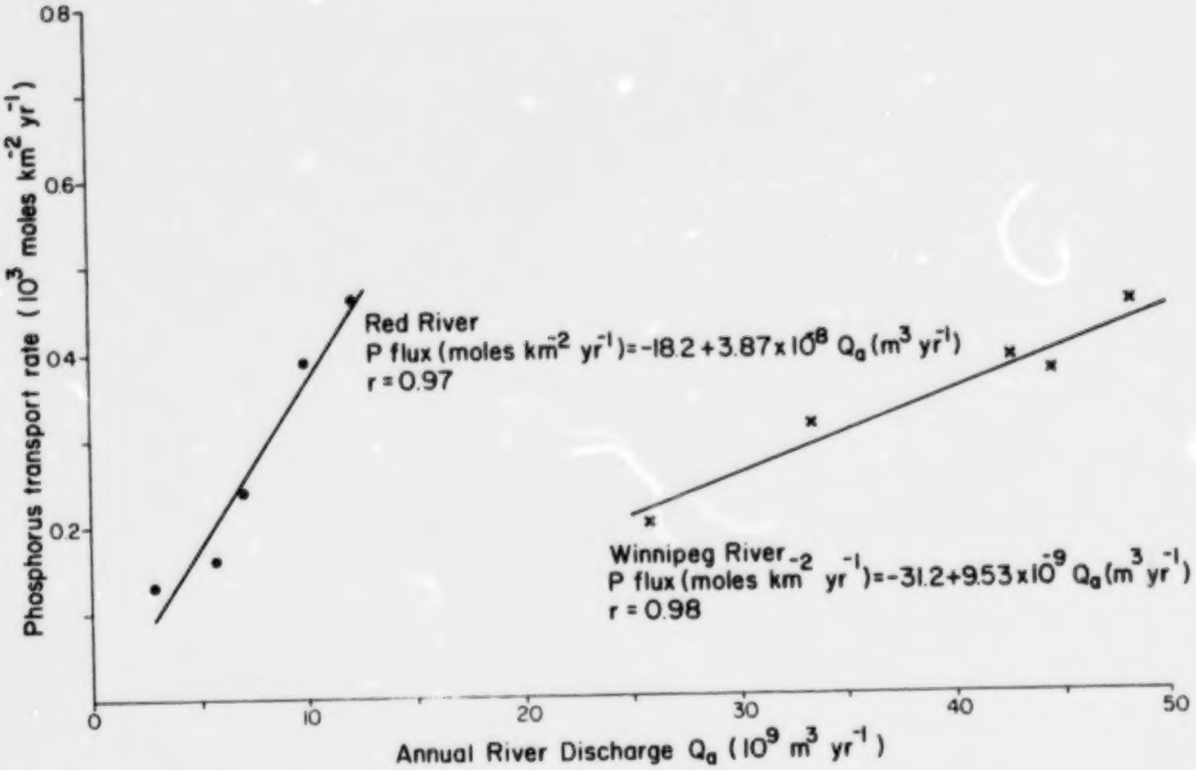


Fig. 7. The relationship between annual river discharge and annual phosphorus transport rate to Lake Winnipeg (from Brunskill *et al.* 1980)

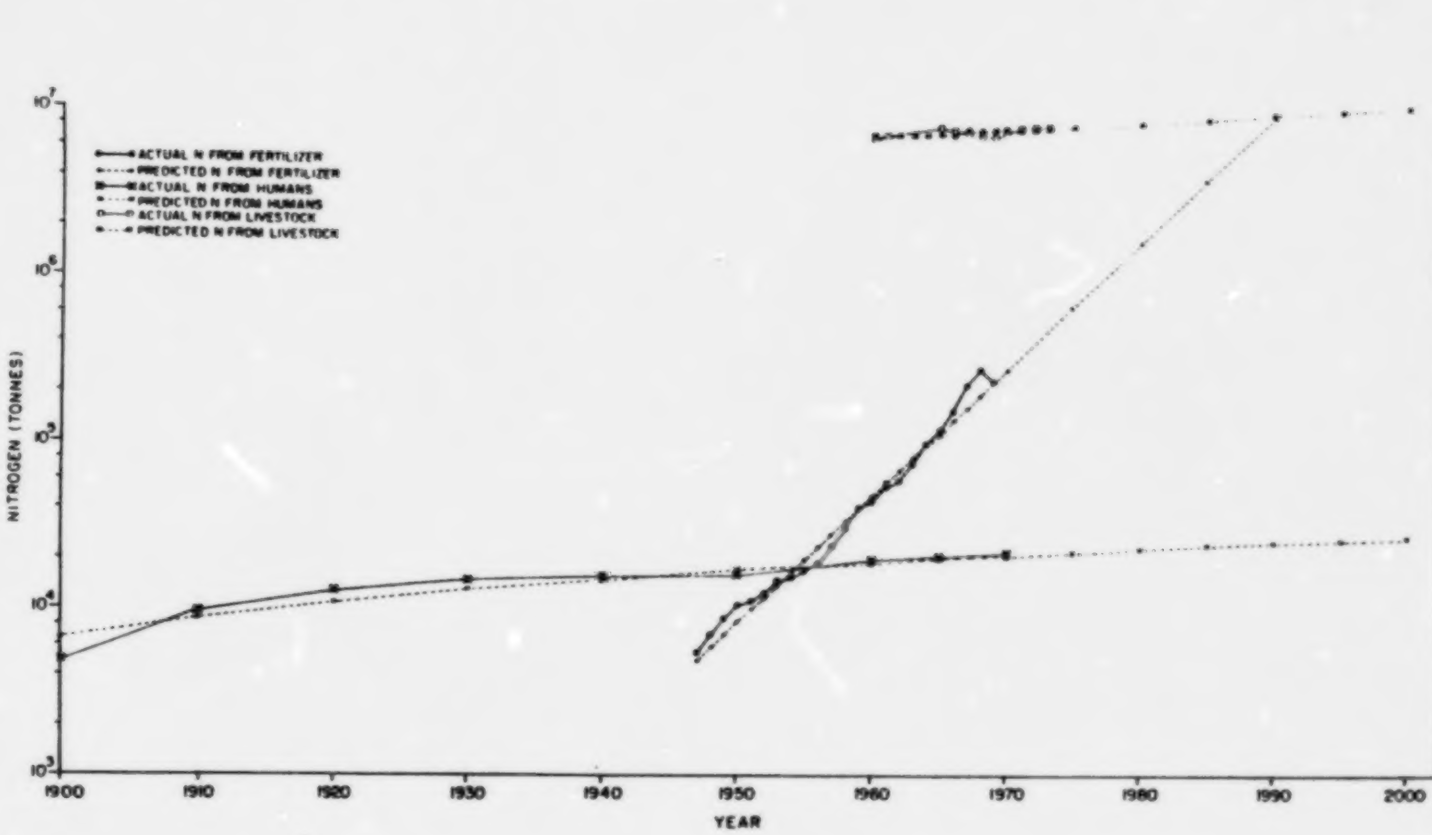


Fig. 8. Historical and extrapolated trends in the annual release of nitrogen to the land and water of the Lake Winnipeg sedimentary drainage area (from Brunskill *et al*. 1980).

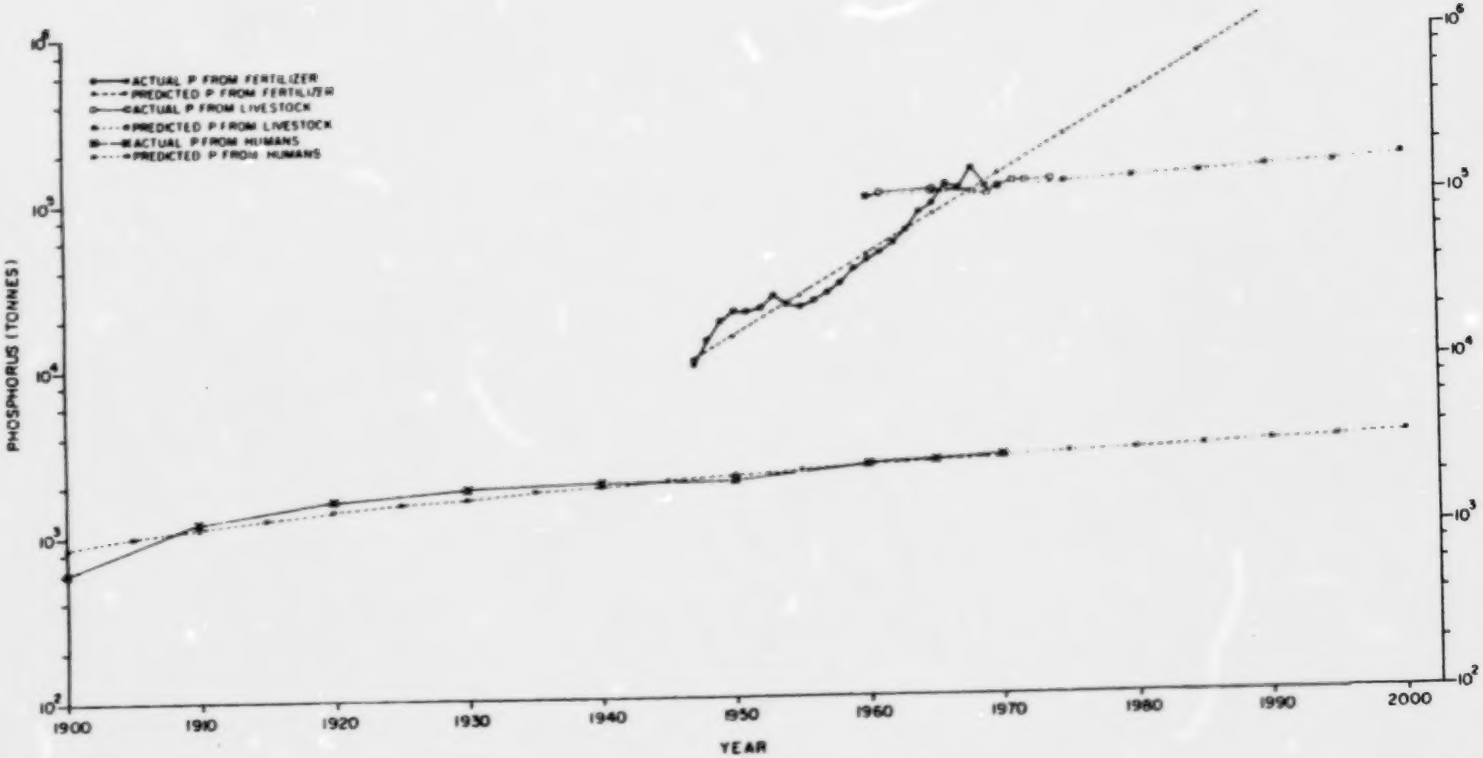
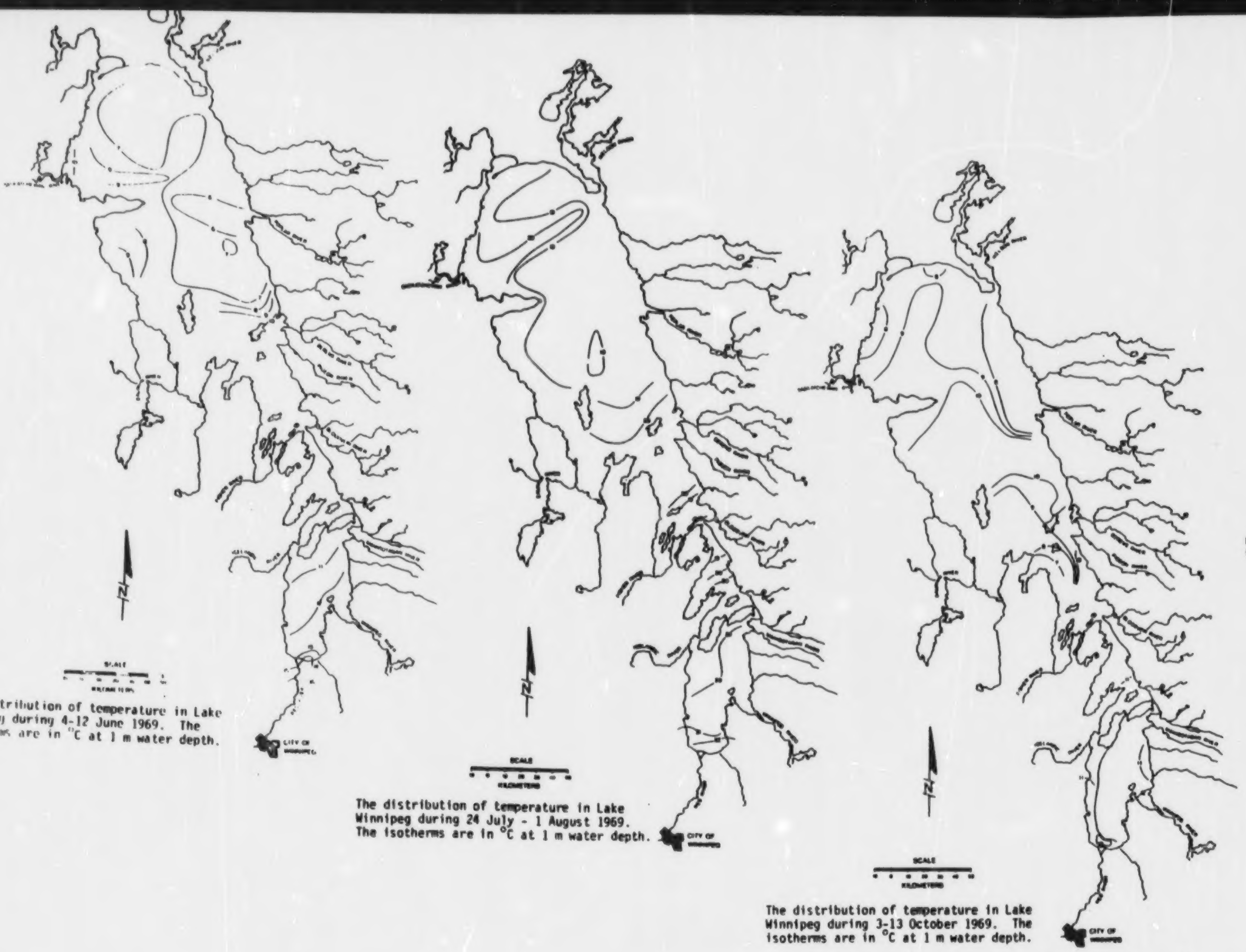


Fig. 9. Historical and extrapolated trends in the annual release of phosphorus to the land and water of the Lake Winnipeg sedimentary drainage area (from Brunskill *et al*. 1980).



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The distribution of temperature in Lake Winnipeg during 4-12 June 1969. The isotherms are in °C at 1 m water depth.

The distribution of temperature in Lake Winnipeg during 24 July - 1 August 1969. The isotherms are in °C at 1 m water depth.

The distribution of temperature in Lake Winnipeg during 3-13 October 1969. The isotherms are in °C at 1 m water depth.

Fig. 10. Spring, summer and fall thermal plumes induced by rivers entering Lake Winnipeg (from Brunskill et al. 1979).

the spatial and temporal distributions of conductivity and major elements are controlled primarily by the river source (Precambrian Shield or sedimentary watersheds) and the extent of the river plumes in the lake (Brunskill *et al.* 1979). Dissolved oxygen concentrations are always near or at saturation levels. The entire mass of water is replaced every 3 to 4.5 years. This replacement time is considerably shorter than that of the larger St. Lawrence Great Lakes (21-185 years) which are much deeper (61-148m) and are influenced by relatively small watersheds and rivers.

Biotic Influences

In addition to influencing the physical and chemical regimes of Lake Winnipeg, incurrent rivers indirectly affect the distribution and magnitude of primary production and directly affect the distributions of some crustacean zooplankters.

Primary productivity in the southern basin is expected to be higher than its northern basin counterpart since the southern basin is warmer for a longer period each year and since it receives higher nutrient loads from incurrent rivers. However, the higher sediment loads increase turbidity in the southern basin. Consequently, primary productivity in the south basin is limited by a high attenuation of solar energy (Table 2).

Some species of copepods and cladocerans consistently inhabit only lake areas that are near river plumes. Other crustacean assemblages only enter the lake via the Saskatchewan and Warpath Rivers while a third

Table 2. Biomass and production estimates of major trophic components in Lake Winnipeg.

Component	Lake area					
	North basin		Channel		South basin	
	B*	P*	B*	P*	B*	P*
River input or organic carbon (Brunskill)		14				170
Phytoplankton (Kling,Fee)	27	440	5	160	15	380
Zooplankton (Patalas)	13	26			26	52
Benthos						
P. hoyi	1	2.3	2.2	7.4	0	0
H. limbata	0.5		2.45	7.4	2.14	6.5
H. rigida (Flannigan)	0	0	1.2	3.7	0.62	1.9
Chironomids	4.2	13.2	2.1	7.5	3.7	13.7
Oligochaetes (Saether,Chang)	2.2	9.1	0.57	1.2	2.2	5.9
Σ	7.9	46.3	8.52	27.2	8.66	28.0
MEAN ANNUAL COMMERCIAL FISH YIELDS (1973-82)[a.]						
Whitefish	0.0586		0.0570		0.0469[b.]	
Walleye	0.0169		0.1370		0.2490	
Sauger	0.0065		0.2280		0.2560	

* B, biomass = $g(wet)m^{-2}$; P, productivity = $g(wet)m^{-2}year^{-1}$

a. Yields from Table 37, incongruencies exist between surface areas used in Table 2 and Table 37.

b. These whitefish were probably caught in the channel and delivered to packing sheds in the south basin.

group is distributed throughout the lake. Patalas (1981) found that Lake Winnipeg's zooplankton community has remained relatively stable (in terms of species composition) since 1929. He speculates that increased nutrient loading has caused zooplankton biomass to double since 1929. Patalas (pers. comm.) estimates that the biomass and productivity of zooplankton in the northern basin is 13 g (wet) m^{-2} and 26 g (wet) $m^{-2}yr^{-1}$, respectively. In the south basin, zooplankton biomass and productivity are approximately twice as great as their northern basin counterparts.

Flannigan and Cobb (1981) documented the disappearance of two Trichoptera species from the benthos of southern Lake Winnipeg and reductions in the spatial distributions of two other caddisfly species that occurred since 1928. They attributed these changes to anthropogenically induced acceleration of eutrophication processes. The disappearance of an amphipod, _Pontoporeia hoyi_, and a decline in the south basin densities of a mayfly larva, _Hexagenia limbata_, were attributed to the same cause Flannigan 1981).

Preliminary estimates of biomass and productivity of various organisms and trophic assemblages (Table 2) were provided by several staff members of the Freshwater Institute who participated in a survey cruise on Lake Winnipeg in 1969.

Relatively few forage fish data sets have been collected from Lake Winnipeg. Kristofferson (1985) monitored relative abundances of yellow perch, white bass, ciscoes and emerald shiners using trawl nets from 1976-83. Spatial and temporal changes in the distribution and body size of emerald shiners in the lower reaches and mouth of the Red River were monitored during the summers of 1983 and 1984 (Lysack, unpublished report).

Age compositions and age-specific mean lengths and mean weights of walleyes (Table 3), saugers (Table 4) and whitefish (Table 5) were tabulated from annual stock assessment programs conducted by regional staff from 1972-83. From 1972-78, the annual stock assessment programs were not standardized over the entire lake. Whitefish data are available only from the northern basin from 1972 to 1978. Walleye and sauger data were not collected from the northern basin from 1972-78. Sampling of walleyes and saugers in the southern basin commenced in 1976. Annual data sets from the channel area have been sporadically available from 1979-83. In some years, too few fish (<250) were collected from the channel to make analyses worthwhile. Sex and maturity data from all three species are not available for the period from 1972-78. The imposition of three maturity categories (immature, developing and mature) precluded meaningful analysis of maturity regimes in most cases during 1979 (Lysack 1980).

Data collected during the annual commercial catch sampling programs were pooled according to major lake areas (Tables 6-10). Samples from packing sheds at Big Black River, Grand Rapids, Gull Bay, George Island and Warren Landing comprised the north basin pool, samples from

Table 3. Age-specific numbers, frequencies, mean lengths and mean weights of experimentally caught walleyes from the three major areas of Lake Winnipeg, 1976-83.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
South basin	1976	0	7	0.41	139	34
		1	45	2.67	235	150
		2	963	57.12	324	376
		3	305	18.09	344	474
		4	283	16.79	391	715
		5	44	2.61	467	1327
		6	35	2.08	490	1523
		7	4	0.24	536	2090
			Σ = 1686			
	1977	0	5	0.37	113	18
		1	63	4.69	217	112
		2	339	25.22	314	328
		3	622	46.28	359	490
		4	89	6.62	324	404
		5	131	9.75	385	716
		6	43	3.20	403	841
		7	18	1.34	494	1549
		8	3	0.22	520	1687
			Σ = 1313			

Table 3, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1978	1	11	0.79	201	105
		2	745	53.33	312	347
		3	324	23.19	343	457
		4	192	13.74	363	582
		5	43	3.08	356	613
		6	73	5.23	445	1137
		7	7	0.50	474	1360
		8	2	0.14	576	2400
			Σ = 1397			
	1979	1	5	0.71	186.80	103.60
		2	35	4.96	220.20	149.34
		3	143	20.25	340.25	422.26
		4	259	36.69	353.19	474.46
		5	188	26.63	366.82	550.53
		6	59	8.36	405.98	747.85
		7	12	1.70	421.58	895.42
		8	2	0.28	495.00	1425.00
		9	3	0.42	487.33	1326.67
			Σ = 706			

Table 3, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1980	0	1	0.27	88.00	10.00
		1	0			
		2	2	0.53	229.00	125.00
		3	24	6.40	317.29	360.21
		4	158	42.13	365.57	548.65
		5	50	13.33	384.20	654.40
		6	83	22.13	402.10	755.72
		7	22	5.87	452.73	1033.18
		8	33	8.80	459.12	1118.79
		9	2	0.53	414.00	720.00
			$\Sigma =$ 375			
	1981	2	12	2.46	268.50	261.67
		3	205	42.09	328.86	402.83
		4	53	10.88	367.09	561.96
		5	125	25.67	397.54	734.68
		6	23	4.72	398.78	757.17
		7	59	12.11	414.20	845.59
		8	5	1.03	427.20	1022.00
		9	5	1.03	468.80	1218.00
			$\Sigma =$ 828			

Table 3, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
North basin	1979	3	5	13.89	295.40	294.00
		4	90	25.00	322.34	388.22
		5	124	34.44	337.07	460.73
		6	77	21.39	366.21	603.90
		7	46	12.78	405.87	815.65
		8	15	4.17	430.20	1014.00
		9	3	0.83	451.67	1090.00
			Σ = 360			
	1980	1	1	0.35	126.00	30.00
		3	4	1.38	204.50	95.00
		4	17	5.88	330.71	425.88
		5	57	19.72	361.81	534.04
		6	112	38.75	382.40	652.32
		7	59	20.42	403.92	764.41
		8	34	11.76	441.24	1017.06
		9	3	1.04	442.67	1160.00
		10	2	0.69	389.00	705.00
			Σ = 289			

Table 3, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1981	1	1	0.23	156.00	30.00
		2	4	0.94	212.00	102.50
		3	7	1.64	284.86	280.00
		4	58	13.62	329.66	408.10
		5	142	33.33	370.01	565.07
		6	122	28.64	398.28	722.87
		7	54	12.68	414.44	811.48
		8	32	7.51	419.88	858.13
		9	6	1.41	445.67	985.00
			Σ = 426			
	1982	3	2	0.72	269.00	215.00
		4	12	4.32	338.00	464.17
		5	11	3.96	341.27	466.36
		6	57	20.50	379.61	643.16
		7	143	51.44	413.96	858.67
		8	40	14.39	435.35	1060.75
		9	12	4.32	452.83	1065.00
		10	1	0.36	510.00	1390.00
			Σ = 278			

Table 3, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1983	2	3	0.70	286.67	263.33
		3	41	9.58	320.73	373.17
		4	147	34.35	349.74	506.94
		5	136	31.78	385.97	681.32
		6	64	14.95	420.69	911.72
		7	31	7.24	459.03	1215.81
		8	4	0.93	492.50	1505.00
		9	2	0.47	519.00	1890.00
			$\Sigma =$ 428			

Table 4. Age-specific numbers, frequencies, mean lengths and mean weights of experimentally caught saugers from the three major areas of Lake Winnipeg, 1976-83.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
South basin	1976	0	20	1.49	159	42
		1	215	16.06	211	91
		2	423	31.59	264	189
		3	530	39.58	311	312
		4	131	9.78	339	419
		5	16	1.19	381	576
		6	2	0.15	331	680
		7	2	0.15	450	1080
			Σ = 1339			
	1977	0	33	1.16	176	53
		1	401	14.15	218	97
		2	946	33.39	261	174
		3	1082	38.19	298	267
		4	315	11.12	320	336
		5	43	1.52	344	443
		6	12	0.42	382	603
		7	1	0.04	396	740
			Σ = 2833			
	1978	1	6	0.41	213	93
		2	359	24.74	259	182
		3	816	56.24	293	275
		4	242	16.68	319	374
		5	21	1.45	356	530
		6	2	0.14	464	1060
		7	5	0.34	302	304
			Σ = 1451			

Table 4, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1979	2	16	2.39	195.00	97.69
		3	69	10.31	283.22	243.77
		4	275	41.11	292.58	263.76
		5	268	40.06	300.51	286.29
		6	38	5.68	307.55	300.11
		7	2	0.30	297.00	265.00
		8	1	0.15	306.00	350.00
			Σ = 669			
	1980	0	1	0.22	92.00	5.00
		1	2	0.44	165.00	42.00
		2	2	0.44	187.00	80.00
		3	5	1.09	262.80	179.00
		4	49	10.70	276.57	225.00
		5	143	31.22	298.31	267.35
		6	152	33.19	308.88	302.24
		7	68	14.85	320.75	334.65
		8	27	5.90	331.93	369.81
		9	7	1.53	322.57	329.29
		10	2	0.44	359.50	470.00
			Σ = 458			

Table 4, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1981	1	6	0.37	139.67	30.00
		2	117	7.19	186.91	77.52
		3	191	11.73	227.14	130.62
		4	101	6.20	285.54	255.25
		5	316	19.41	303.21	302.31
		6	527	32.37	316.36	257.91
		7	309	18.98	324.58	400.74
		8	54	3.32	332.41	440.00
		9	6	0.37	343.33	500.00
		10	1	0.06	372.00	590.00
		Σ	= 1,658			
	1982	1	5	0.58	116.80	23.00
		2	89	10.39	211.21	102.42
		3	326	38.04	225.70	131.15
		4	174	20.30	276.29	242.76
		5	90	10.50	311.80	346.11
		6	108	12.60	331.24	426.39
		7	60	7.00	347.10	505.50
		8	4	0.47	364.00	587.50
		9	1	0.12	380.00	710.00
		Σ	= 857			

Table 4, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1983	1	5	1.56	184.00	40.00
		2	27	8.44	238.07	109.63
		3	94	29.38	263.19	171.60
		4	57	17.81	295.96	265.35
		5	64	20.00	327.78	358.02
		6	49	15.31	350.61	480.10
		7	20	6.25	374.70	608.25
		8	3	0.94	413.33	903.33
		9	1	0.31	446.00	1220.00
			Σ = 320			
Channel	1979	2	2	0.96	191.00	70.00
		3	21	10.05	233.43	123.81
		4	49	23.44	270.98	191.43
		5	81	38.76	284.20	221.85
		6	28	13.40	300.96	270.71
		7	19	9.09	310.26	298.95
		8	7	3.35	339.57	385.71
		9	1	0.48	346.00	370.00
		10	1	0.48	346.00	380.00
			Σ = 209			

Table 4, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1980	1	12	3.15	153.50	35.83
		2	23	6.04	179.65	50.87
		3	19	4.99	239.37	133.16
		4	94	24.67	266.15	185.43
		5	125	32.81	280.03	218.96
		6	70	18.37	297.17	264.00
		7	32	8.40	311.00	308.75
		8	4	1.05	323.50	352.50
		9	1	0.26	422.00	710.00
		10	1	0.26	396.00	630.00
			Σ = 381			
	1982	1	1	0.12	180.00	30.00
		2	36	4.28	211.44	68.06
		3	44	5.23	232.45	93.86
		4	58	6.89	268.79	171.21
		5	57	6.77	296.11	257.37
		6	109	12.95	317.96	329.72
		7	152	18.05	326.97	387.96
		8	169	20.07	353.88	537.72
		9	145	17.22	372.48	647.59
		10	48	5.70	397.58	815.63
		11	16	1.90	404.38	880.31
		12	4	0.48	429.00	1135.00
		13	3	0.36	449.33	1263.33
			Σ = 842			

Table 4, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1983	2	3	0.35	232.67	90.00
		3	12	1.40	255.50	142.50
		4	42	4.91	297.38	257.62
		5	255	29.79	323.87	369.84
		6	320	37.38	352.74	529.72
		7	178	20.79	376.52	667.64
		8	43	5.02	402.56	853.02
		9	3	0.35	395.33	806.67
			Σ = 856			
North basin	1979	4	8	0.76	279.31	273.75
		5	40	3.81	301.28	305.50
		6	153	14.59	318.74	368.76
		7	223	21.26	335.30	430.00
		8	256	24.40	347.77	486.33
		9	179	17.06	359.79	541.84
		10	68	6.48	378.63	640.15
		11	46	4.39	386.28	706.09
		12	26	2.48	408.92	845.00
		13	18	1.72	375.61	559.44
		14	18	1.72	382.56	650.00
		15	4	0.38	441.75	1127.50
		16	5	0.48	409.20	800.00
		17	0	-	-	-
		18	2	0.19	416.00	770.00
		19	2	0.19	434.00	1040.00
		20	1	0.10	408.00	820.00
			Σ = 1,049			

Table 4, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1980	1	2	0.22	155.00	50.00
		2	2	0.22	193.00	70.00
		3	4	0.44	198.00	85.00
		4	19	2.09	263.16	198.95
		5	84	9.22	290.76	262.38
		6	183	20.09	320.67	360.74
		7	209	22.94	336.58	424.78
		8	201	22.06	352.17	506.02
		9	111	12.18	369.30	579.82
		10	63	6.92	386.97	697.46
		11	20	2.20	409.40	807.00
		12	9	0.99	410.44	842.22
		13	3	0.33	435.33	943.33
		14	1	0.11	460.00	1150.00
			Σ = 911			
	1981	1	1	0.12	146.00	30.00
		2	4	0.48	258.00	157.50
		3	25	3.00	275.76	222.40
		4	72	8.65	307.50	321.22
		5	184	22.16	329.77	385.22
		6	258	31.01	345.02	443.26
		7	140	16.83	361.20	535.71
		8	100	12.02	368.58	570.90
		9	37	4.45	393.14	696.76
		10	7	0.84	398.00	748.57
		11	2	0.24	377.00	660.00
		12	1	0.12	456.00	850.00
		13	1	0.12	448.00	1040.00
			Σ = 832			

Table 4, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1982	2	1	0.12	162.00	80.00
		3	2	0.24	237.00	140.00
		4	2	0.24	223.00	115.00
		5	15	1.77	300.53	301.33
		6	47	5.56	328.00	410.43
		7	162	19.15	336.73	467.90
		8	261	30.85	359.74	589.00
		9	218	25.77	376.18	691.93
		10	80	9.46	393.48	815.25
		11	37	4.37	409.19	965.41
		12	17	2.07	420.00	1020.00
		13	2	0.24	444.00	1170.00
		14	2	0.24	439.00	1270.00
			Σ = 846			
	1983	2	3	0.25	204.67	106.67
		3	12	0.99	266.00	215.00
		4	80	6.60	313.20	339.38
		5	335	27.64	334.50	429.55
		6	480	39.60	359.40	574.90
		7	229	18.89	383.72	735.55
		8	65	5.36	410.74	980.00
		9	7	0.58	429.43	1152.86
		10	1	0.08	478.00	1570.00
			Σ = 1212			

Table 5. Age-specific numbers, frequencies, mean lengths and mean weights of experimentally caught whitefish from the three major areas of Lake Winnipeg, 1972-83.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
North basin	1972	2	1	0.05	254	227
		3	27	1.30	310	400
		4	636	30.65	382	777
		5	1274	61.40	417	1038
		6	135	6.51	443	1313
		7	2	0.10	508	1885
			Σ = 2075			
	1973	2	35	1.36	266	253
		3	227	8.85	327	479
		4	827	32.24	380	776
		5	1055	41.13	427	1127
		6	386	15.05	451	1394
		7	33	1.29	478	1728
		8	2	0.08	503	1885
			Σ = 2565			

Table 5, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1974	2	60	4.24	264	237
		3	149	10.53	306	382
		4	346	24.45	381	762
		5	566	40.00	427	1109
		6	267	18.87	455	1392
		7	25	1.77	480	1730
		8	2	0.14	485	1970
			Σ = 1415			
	1975	2	54	1.78	261	239
		3	1059	34.86	312	421
		4	504	16.59	370	707
		5	678	22.32	432	1110
		6	490	16.13	454	1307
		7	175	5.76	468	1457
		8	56	1.84	480	1608
		9	19	0.63	488	1658
		10	2	0.07	495	1890
			Σ = 3038			

Table 5, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1976	2	12	0.37	273	284
		3	341	10.47	291	324
		4	1121	34.41	344	549
		5	533	16.34	380	743
		6	530	16.27	424	1034
		7	407	12.49	449	1236
		8	202	6.20	467	1423
		9	76	2.33	478	1539
		10	32	0.98	491	1693
		11	4	0.12	519	2060
			Σ = 3258			
	1977	2	10	0.46	268	242
		3	174	8.06	289	303
		4	506	23.45	345	521
		5	830	38.46	377	700
		6	277	12.84	410	911
		7	161	7.46	437	1088
		8	130	6.02	457	1266
		9	48	2.22	474	1399

Table 5, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1977	10	15	0.70	472	1409
		11	5	0.23	499	1932
		12	2	0.09	497	1500
			Σ = 2158			
	1978	2	16	0.39	257	227
		3	148	3.59	302	371
		4	1214	29.41	345	544
		5	1909	46.25	380	733
		6	621	15.04	409	942
		7	140	3.39	443	1189
		8	55	1.33	471	1440
		9	23	0.56	482	1589
		10	2	0.05	524	2380
			Σ = 4128			

Table 5, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1979	2	1	0.07	252.00	260.00
		3	24	1.69	295.50	361.25
		4	249	17.56	343.78	601.29
		5	545	38.43	375.39	781.12
		6	400	28.21	392.73	898.25
		7	138	9.73	407.19	1010.00
		8	46	3.24	428.72	1215.87
		9	10	0.71	453.90	1485.00
		10	1	0.07	508.00	2080.00
		11	3	0.21	516.00	2146.67
		14	1	0.07	556.00	3420.00
			Σ = 1,418			
	1980	2	6	0.29	247.33	213.33
		3	140	6.70	299.36	366.00
		4	246	11.76	337.99	508.57
		5	612	29.27	372.54	784.84
		6	693	33.14	392.27	926.96
		7	264	12.63	406.11	1034.39
		8	82	3.92	417.79	1124.88

Table 5, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1980	9	33	1.58	439.97	1336.36
		10	13	0.62	458.46	1555.38
		11	2	0.10	496.00	1940.00
			Σ = 2,091			
	1981	2	24	0.79	279.50	314.58
		3	482	15.85	315.58	457.78
		4	831	27.33	370.74	762.01
		5	1066	35.05	394.82	913.72
		6	530	17.43	406.31	1001.42
		7	93	3.06	424.82	1162.04
		8	14	0.46	436.29	1377.14
		9	0		-	-
		10	1	0.03	492.00	1500.00
			Σ = 3,041			

Table 5, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
	1982	3	78	5.36	291.13	347.18
		4	510	35.05	321.33	486.56
		5	326	22.41	367.23	728.59
		6	350	24.05	396.90	934.57
		7	159	10.93	406.70	1021.64
		8	21	1.44	413.81	1091.43
		9	6	0.41	439.00	1325.00
		10	4	0.27	412.00	1100.00
		11	1	0.07	522.00	2010.00
			Σ = 1,455			
	1983	2	1	0.03	232.00	180.00
		3	24	0.75	287.50	357.08
		4	647	20.35	317.83	470.45
		5	1279	40.22	345.98	633.25
		6	672	21.13	391.25	901.16
		7	452	14.21	415.59	1107.21
		8	91	2.86	429.71	1244.73
		9	13	0.41	438.62	1411.54
		10	1	0.03	424.00	1270.00
			Σ = 3,180			

Table 5, cont'd.

Area	Year	Age (years)	No. fish	Frequency(%)	Mean length (mm)	Mean weight (gm)
Channel	1980	2	8	4.12	305.25	481.25
		3	25	12.89	329.68	600.40
		4	64	32.99	354.94	747.34
		5	65	33.51	374.89	893.85
		6	24	12.37	389.17	987.92
		7	8	4.12	407.50	1098.75
			Σ = 194			
	1982	3	22	3.27	296.82	377.95
		4	159	23.63	330.04	563.96
		5	181	26.89	372.94	798.67
		6	201	29.87	398.85	965.02
		7	90	13.37	414.49	1221.22
		8	16	2.38	427.50	1291.25
		9	3	0.45	461.33	1600.00
		10	1	0.15	438.00	1300.00
			Σ = 673			

Table 6. Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from Lake Winnipeg, 1979.

Season	Age (years)	Species													
		Walleye						Sauger						Whitefish	
		North		Channel		South		North		Channel		South		North		Channel	
		no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Summer	2	1	0.08			2	0.30							1	0.04		
	3	3	0.25	19	18.10	205	31.20					4	0.66	4	0.16	1	0.20
	4	30	2.49	27	25.71	123	18.72	9	3.57	37	7.14	67	11.00	123	4.96	28	5.74
	5	182	15.12	35	33.33	100	15.22	62	24.60	223	43.05	296	48.60	976	39.34	223	45.70
	6	377	31.31	4	3.81	95	14.46	104	41.27	199	38.42	151	24.79	954	38.45	146	29.92
	7	531	44.10	15	14.29	97	14.76	50	19.84	50	9.65	48	7.88	313	12.62	53	10.86
	8	69	5.73	4	3.81	16	2.44	19	7.54	9	1.74	22	3.61	66	2.66	13	2.66
	9	6	0.50			3	0.46	7	2.78			15	2.46	13	0.52	8	1.64
	10	4	0.33			2	0.30	1	0.40			6	0.99	14	0.56	7	1.43
	11	1	0.08											8	0.32	2	0.41
	12					1	0.15							5	0.20	4	0.82
	13													2	0.08		
	14													1	0.04		
	15													1	0.04		
	$\bar{L}$(mm)	425.62		373.10		389.16		329.45		299.25		316.44		404.80		402.55	
	$\bar{W}$(gm)	951.55		673.14		768.53		403.25		296.66		407.36		873.93		953.69	
	$\bar{X}$(years)	6.38		4.77		4.64		6.13		5.56		5.54		4.97		5.72	

Table 6, cont'd.

Season	Age (years)	Species															
		Walleye						Sauger						Whitefish			
		North		Channel		South		North		Channel		South		North		Channel	
		no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Fall	2			1	0.22	8	0.80	6	2.41	2	0.40	11	1.51	7	2.81		
	3			29	6.50	413	41.39	50	20.08	52	10.40	288	39.45	43	17.27		
	4	10	4.02	70	15.70	436	43.64	92	36.95	258	51.60	402	55.07	114	45.78		
	5	87	34.94	166	37.22	101	10.11	71	28.51	164	32.80	28	3.84	62	24.90		
	6	92	36.95	74	16.59	22	2.20	27	10.84	19	3.80	1	0.14	16	6.43		
	7	48	19.28	80	17.94	10	1.00	2	0.80	5	1.00			3	1.20		
	8	11	4.42	25	5.61	4	0.40	1	0.40								
	9	1	0.40			3	0.30										
	10													1	0.40		
	11					1	0.10							1	0.40		
	14													1	0.40		
	$\bar{L}$(mm)	427.34		400.06		359.61		317.49		315.98		304.55		395.89			
	$\bar{W}$(gm)	1036.87		833.79		514.92		421.06		362.14		320.06		774.30			
	$\bar{A}$(years)	5.86		5.39		5.29		5.32		4.62		5.24					

Table 7. Age compositions and mean lengths and weights of commercial catches in northern and southern Lake Winnipeg, 1980. Numbers in parentheses are percentage frequencies.

Species	Area	Season	Age (years)										Mean length (mm)	Mean weight (gm)
			2	3	4	5	6	7	8	9	10	11		
Sauger	North	Summer		43(4.11)	250(32.76)	343(32.76)	281(26.84)	104(9.93)	25(2.39)	1(.10)			305.45	309.83
		Fall		8(1.07)	140(18.69)	237(31.640	238(31.78)	108(13.48)	23(3.07)	2(.27)				
	South	Summer			69(13.80)	211(42.20)	143(28.60)	59(11.80)	17(3.40)	1(.20)			311.59	328.24
		Fall		7(.70)	302(30.20)	556(55.60)	123(12.30)	9(.90)	2(.20)	1(.10)			320.86	375.74
Walleye	North	Summer		1(.11)	18(1.92)	110(11.75)	381(40.71)	268(28.63)	127(13.57)	22(2.35)	9(.96)		415.54	893.40
		Fall	27(5.41)	30(6.01)	113(22.65)	92(18.44)	200(40.08)	24(4.81)	13(2.61)				410.38	877.11
	South	Summer			9(1.81)	151(30.32)	194(38.96)	90(18.07)	40(8.03)	11(2.21)	2(.40)	1(.20)	368.72	611.71
		Fall	176(35.20)	92(18.40)	137(27.40)	46(9.20)	30(6.00)	7(1.40)	11(2.20)	1(.20)			372.62	659.26
Whitefish	North	Summer		1(.07)	122(8.24)	601(40.58)	510(34.44)	186(12.56)	47(3.17)	12(.81)			412.51	929.68
		Fall		6(1.20)	56(11.20)	240(48.00)	163(32.60)	31(6.20)	1(.20)	3(.60)			404.26	842.32[1]

[1] dressed weight.

Table 8. Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from Lake Winnipeg, 1981. Numbers in parentheses are frequencies (%).

Species	Area	Season	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	Mean length (mm)	Mean weight (gm)	mean age (years)
Walleye	North	Summer			2 (.2)	47 (4.76)	103 (10.44)	223 (22.59)	471 (47.72)	125 (12.66)	9 (.91)	4 (.41)	1 (.1)	2 (.2)	418.30	914.47	6.58
		Fall															
	Channel	Summer			82 (16.4)	54 (10.8)	143 (28.6)	95 (19.0)	122 (24.4)	2 (.4)	2 (.4)				388.75	724.82	5.27
		Fall		2 (.27)	119 (15.89)	119 (15.89)	245 (32.71)	130 (17.36)	125 (16.69)	8 (1.07)	1 (.13)				409.46	881.15	5.06
	South	Summer		4 (1.6)	172 (68.80)	23 (9.20)	35 (14.00)	9 (3.60)	7 (2.80)						326.40	414.36	3.58
		Fall	1 (.1)	258 (25.8)	476 (47.60)	156 (15.60)	92 (9.20)	12 (1.20)	4 (0.4)	1 (0.1)					341.45	503.15	3.14
Sauger	Channel	Summer			3 (1.20)	80 (32.13)	116 (46.59)	40 (16.06)	7 (2.81)	3 (1.2)					351.16	459.40	4.91
		Fall			1 (0.40)	109 (43.60)	118 (47.20)	19 (7.60)	2 (0.80)	1 (0.4)					330.30	446.59	4.66
	South	Summer		5 (0.44)	384 (34.04)	591 (52.39)	133 (11.79)	14 (1.24)	1 (0.09)						309.95	327.69	3.80
		Fall			83 (16.60)	302 (60.40)	101 (20.20)	13 (2.60)	1 (0.20)						313.94	373.78	4.09
Whitefish	North	Summer*				138 (13.80)	569 (56.90)	246 (24.60)	33 (3.30)	8 (0.8)	4 (0.4)	2 (0.2)			410.39	909.42	5.22
		Channel			3 (0.6)	169 (33.80)	270 (54.00)	52 (10.40)	4 (0.80)	1 (0.2)	1 (0.2)				413.97	952.80	4.78

* Grand Rapids data were omitted since dressed weights were recorded.

Table 9. Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from the three major areas of Lake Winnipeg, 1982. Numbers in parentheses are percentages.

Species	Area	Season	Age (years)														Mean length	Mean weight	Mean age
			1	2	3	4	5	6	7	8	9	10	11	12	13	14			
Walleye	North	Summer					39 (5.2)	218 (29.07)	290 (36.67)	171 (22.80)	29 (3.87)	3 (0.4)					443.06	1097.04	6.92
		Fall			2 (0.4)	35 (7.000)	158 (31.60)	202 (40.40)	80 (16.00)	20 (4.00)	1 (0.2)	1 (0.2)					442.01	1155.96	5.80
	Channel	Summer			37 (7.41)	152 (30.46)	75 (15.03)	132 (26.45)	87 (17.43)	15 (3.01)	1 (0.20)						388.31	731.16	5.26
		Fall			62 (12.40)	127 (25.40)	71 (14.20)	83 (16.60)	96 (19.20)	53 (10.60)	7 (1.40)	1 (0.20)					431.60	1084.04	5.43
	South	Summer		1 (0.13)	339 (45.26)	293 (39.12)	29 (3.87)	44 (5.87)	17 (2.27)	22 (2.94)	3 (0.40)	1 (0.13)					360.63	587.80	3.91
		Fall		49 (4.90)	558 (55.80)	282 (28.20)	48 (4.80)	42 (4.20)	10 (1.00)	9 (0.9)	1 (0.1)	1 (0.1)					363.19	602.11	3.55
Sauger	Channel	Summer				1 (0.13)	2 (0.27)	22 (2.94)	65 (8.69)	214 (28.61)	217 (29.01)	131 (17.51)	65 (8.69)	22 (2.94)	7 (0.94)	2 (0.77)	361.72	589.30	8.92
		Fall			21 (4.20)	102 (20.40)	171 (34.20)	157 (31.40)	44 (8.80)	4 (0.80)	1 (0.20)						328.37	427.22	5.23

Table 9, cont'd.

Species	Area	Season	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Mean length	Mean weight	Mean age
	South	Summer				18 (7.23)	51 (20.48)	31 (12.45)	61 (24.50)	67 (26.91)	18 (7.23)	2 (0.80)	1 (0.40)				310.96	332.01	6.70
		Fall	3 (0.6)	46 (9.20)	310 (62.00)	123 (24.60)	11 (2.20)	6 (1.20)	1 (0.20)								296.96	330.56	3.23
Whitefish	North	Summer				11 (1.10)	109 (10.9)	465 (46.5)	364 (36.4)	47 (4.7)	3 (0.3)	1 (0.1)					407.72	883.27*	6.34
	Channel	Summer				11 (4.4)	39 (15.6)	102 (40.8)	78 (31.2)	19 (7.6)	1 (0.4)						411.67	1082.16	6.23

*dressed weight

Table 10. Age compositions, mean lengths, mean weights and mean weighted ages of commercially caught species from Lake Winnipeg, 1983. Numbers in parentheses are percent frequencies.

Species	Area	Season	Age (years)											Mean length (mm)	Mean weight (gm)	Mean age (years)
			1	2	3	4	5	6	7	8	9	10	11			
Walleye	North	summer			2 (0.27)	52 (6.93)	102 (13.60)	131 (33.87)	254 (21.73)	163 (5.87)	44 (0.13)	1 (0.13)	1	421.97	997.35	6.68
		fall			1 (0.20)	36 (7.20)	50 (10.00)	185 (37.00)	122 (24.40)	79 (15.80)	22 (4.40)	5 (1.00)		433.09	1217.28	6.48
	Channel	fall		6 (1.20)	23 (4.60)	224 (44.80)	160 (32.00)	22 (4.4)	50 (10.00)	6 (1.20)	6 (1.20)	2 (0.40)	1	389.59	745.98	4.78
	South	summer		1 (0.10)	56 (5.62)	393 (39.64)	257 (25.80)	64 (6.43)	85 (8.53)	80 (8.03)	57 (5.72)	1 (0.10)	2 (0.20)	409.37	934.58	5.21
		fall	14 (1.87)	124 (16.53)	184 (24.53)	223 (29.73)	131 (17.47)	48 (6.40)	17 (2.27)	7 (0.93)	2 (0.27)			339.83	527.79	3.79
Sauger	Channel	summer			2 (0.27)	73 (9.73)	229 (30.53)	318 (42.40)	104 (13.87)	21 (2.80)	3 (0.40)			345.86	514.08	5.70
		fall			51 (10.22)	133 (26.65)	136 (27.25)	110 (22.04)	56 (11.22)	13 (2.61)				332.71	435.43	5.05
	South	summer			57 (22.80)	155 (62.00)	32 (12.80)	6 (2.40)						286.35	274.08	3.95
		fall		32 (4.27)	151 (20.16)	402 (53.67)	160 (21.36)	4 (0.53)						305.69	323.58	3.94
Whitefish	North	summer				14 (1.87)	162 (21.60)	339 (45.20)	212 (28.27)	20 (2.67)	3 (0.40)			412.97	1079.45	6.10

Berens River and Matheson Island comprised the channel pool and samples from Gimli and Selkirk comprised the south basin pool. Cases including samples of dressed fish were omitted from the data pools listed on Tables 6-10.

Plots of age-specific mean lengths versus ages of walleyes, saugers and whitefish from major lake areas (Figs. 11-16) reveal a major ageing discrepancy between pre-1979 and post-1979 experimental samples. The pre-1979 growth curves are generally characterized by relatively fewer age groups and relatively higher annual growth increments. The post-1979 growth curves are shifted to include older age classes and depict lower growth increments. This phenomenon is attributed to the change of magnifying instruments used to view fish scales that occurred in 1979. The underestimation of ages of older fish inflates estimates of mortality and growth rates. Consequently, pre-1979 data were not included in statistical tests for long term changes in dynamic processes.

Growth Regimes

Length-weight relationships

Gillnet selectivity affects the slopes of length-weight curves. The youngest fish caught in nets usually have high weight:length ratios implying that the associated data points lie above the true length-weight curve. The points on the length-weight curves of Lake Winnipeg stocks

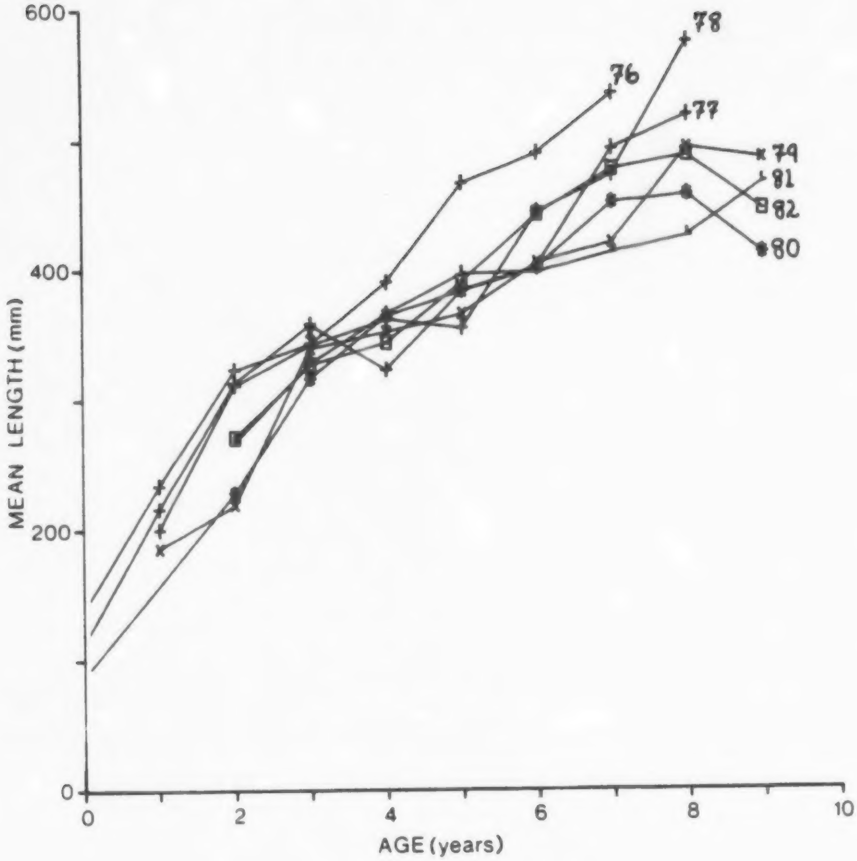


Fig. 11. Age specific mean lengths of south basin walleyes.

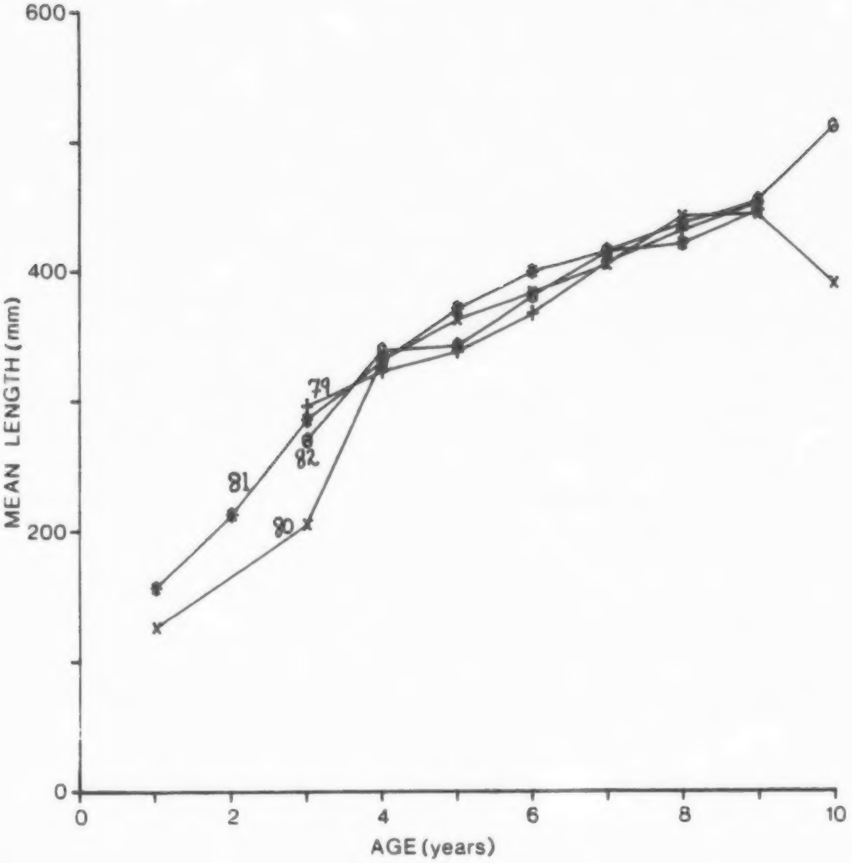


Fig. 12. Age specific mean lengths of north basin walleyes.

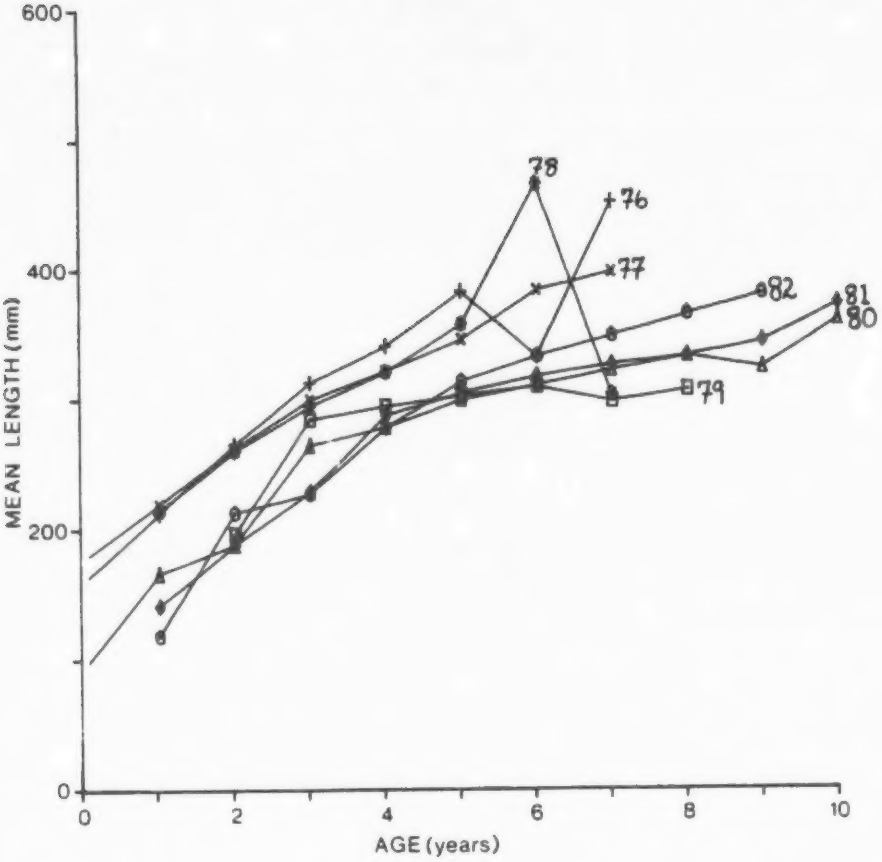


Fig. 13. Age specific mean lengths of south basin saugers.

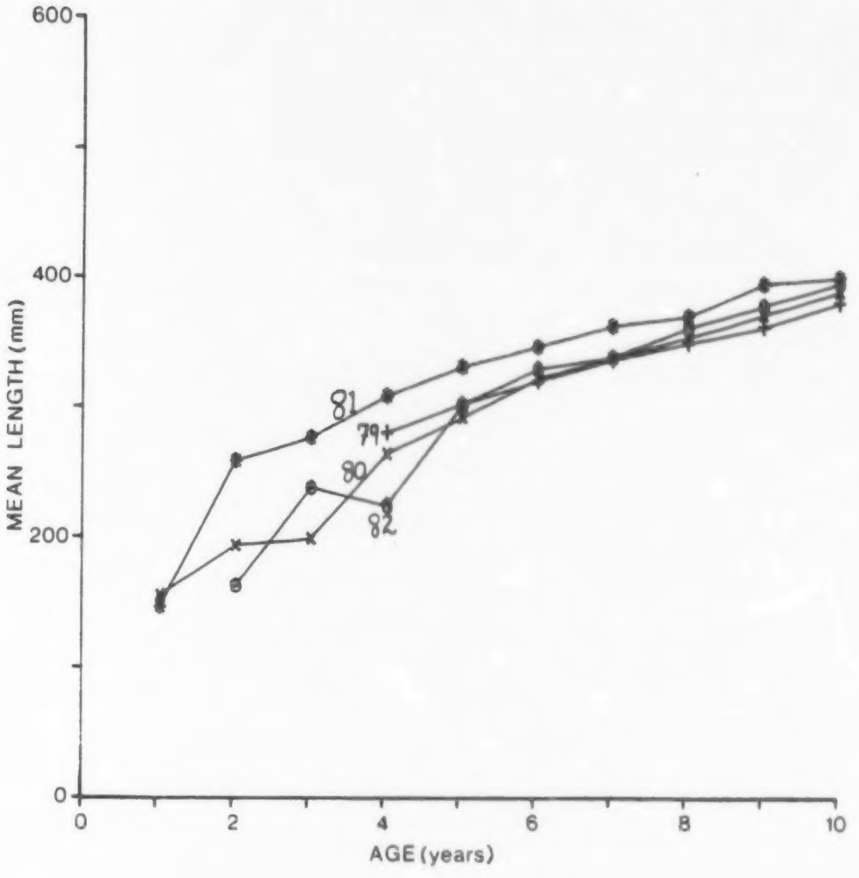


Fig. 14. Age specific mean lengths of north basin saugers.

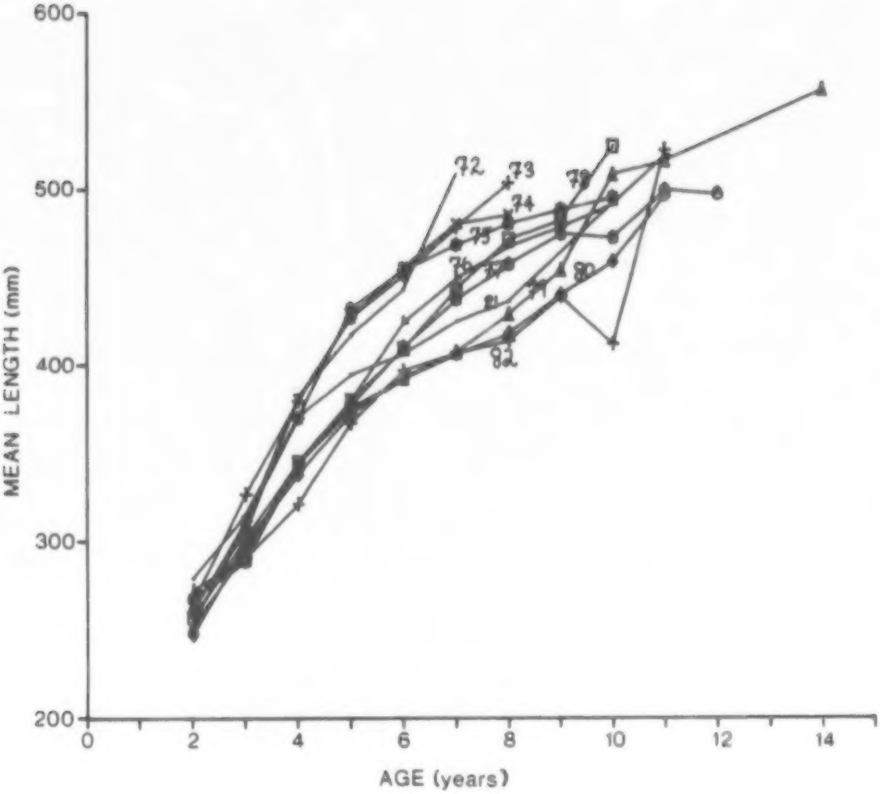


Fig. 15. Age specific mean lengths of north basin whitefish.

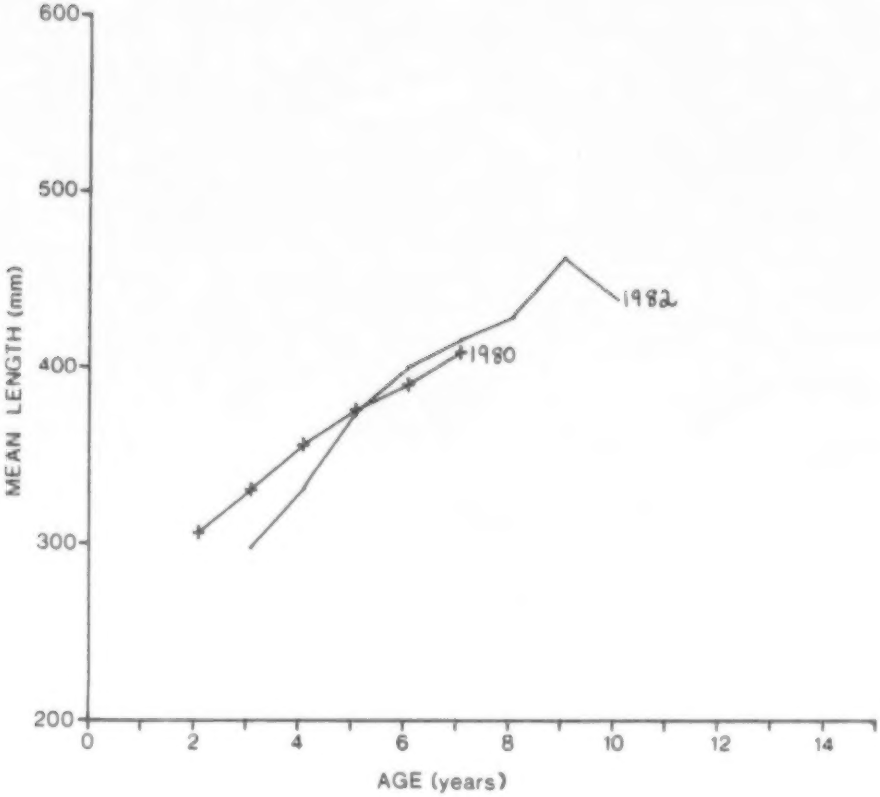


Fig. 16. Age specific mean lengths of channel whitefish.

represent age-specific mean lengths and mean weights and the derived equations represent "age class length-weight relationships. A line fitted through individual lengths and weights would predict lower weights at a given length and have a different slope.

Ricker (1973,1975) stresses that a geometric mean functional (GMF) regression line should be employed when predicting weights from given lengths. GMF length-weight curves of Lake Winnipeg stocks (Table 11) were derived from the least squares regression curves listed in the annual Lake Winnipeg stock assessment reports (Lysack 1980-84). ANCOVA indicates that the slopes and elevations of whitefish length-weight curves have remained essentially static from 1979-83. Results of ANCOVA of north basin and of south basin sauger and walleye stocks (Table 11) are more difficult to interpret since slopes or elevations of the length-weight curves have not increased or decreased monotonically but seem to change erratically from year to year.

Annual estimates of growth rates

The "exponential" growth curves of Lake Winnipeg walleye, sauger and whitefish stocks listed in the annual reports (Lysack 1980-84) were incorrectly derived. These curves were actually "power" curves describing the proportional rate of change in body lengths with respect to the proportional rate of change in time. The correct exponential growth curves describe the proportional rate of change in body length with

Table 11. Geometric mean functional length-weight relationships[a] of walleyes, saugers and whitefish from Lake Winnipeg, 1979-83.

Species	Year	North basin	South basin
Whitefish	1979	$Y = -12.315 + 3.208X$	-
	1980	$Y = -12.717 + 3.271X$	-
	1981	$Y = -11.014 + 2.981X$	-
	1982	$Y = -11.590 + 3.080X$	-
	1983	$Y = -12.197 + 3.190X$	-
slopes F		1.155(d.f.=4,37)	
elevations F		1.565(d.f.=4,41)	
Sauger	1979	$Y = -12.162 + 3.137X$	$Y = - 9.024 + 2.576X$
	1980	$Y = -11.605 + 3.039X$	$Y = -13.008 + 3.267X$
	1981	$Y = -12.343 + 3.156X$	$Y = -11.639 + 3.047X$
	1982	$Y = -11.483 + 3.039X$	$Y = -10.862 + 2.917X$
	1983	$Y = -12.905 + 3.279X$	$Y = -16.196 + 3.819X$
slopes F		0.847(4,55)	16.801 (d.f.=4,36)*
elevations F		6.591(4,59)*	4.209 (d.f.=4,40)*
Walleye	1979	$Y = -12.284 + 3.161X$	$Y = - 9.552 + 2.696X$
	1980	$Y = -10.689 + 2.891X$	$Y = -10.549 + 2.856X$
	1981	$Y = -13.024 + 3.277X$	$Y = -10.725 + 2.899X$
	1982	$Y = -11.380 + 3.004X$	$Y = -10.151 + 2.811X$
	1983	$Y = -13.022 + 3.284X$	$Y = -13.498 + 3.351X$
slopes F		5.945(d.f.=4,31)*	11.096 (d.f.=4,32)*
elevations F		2.166(d.f.=4,35)	2,092 (d.f.=4.36)

*significant at $P = 0.05$

a. $Y = \log_e$ age-specific mean weight (gm)
$X = \log_e$ age-specific mean length (mm)

respect to the rate of change of time (Table 12). Estimates of L_∞ values derived from Walford plots (Table 13), and K and t_o values (Table 14) were used to quantify the von Bertalanffy growth curves listed on Table 12.

In an attempt to simplify the von Bertalanffy equation, Gallucci and Quinn (1979) combined the L_∞ and K constants into a new constant $w = K.L_\infty$ which corresponds to the growth rate near t_o. Pauley (1979) defined a similar statistic, $P = \log (W_\infty.K)$, which measures the angle of the catabolic curve to the abscissa of an age-specific mean weight plot. Since mean weight tends to vary more than mean length, I used the following modified Pauley statistic in this report:

$P = \log_e (L_\infty.K)$ (Table 12). Plots of L_∞ and K values for northern and southern walleye stocks (Fig. 17), northern whitefish (Fig. 18) and northern and southern sauger stocks (Fig. 19) from 1979-83 tend to change in a stereoisometric fashion. P values for northern whitefish decreased dramatically from 1972-1979. From 1979-1983, P values for northern and channel whitefish stocks increased dramatically (Fig. 20). P values for northern and southern walleye stocks fluctuated from year to year but did not increase or decrease dramatically from 1976-83 (Fig. 21). P values for southern saugers were relatively low and stable from 1976-1978. From 1979-1983, P values for northern and channel sauger stocks remained relatively constant while they fluctuated more for southern sauger stocks (Fig. 22).

Table 12. Exponential and von Bertalanffy growth curves of whitefish, walleyes and saugers from Lake Winnipeg, 1972-83.

Species	Area	Year	Growth curve					
			Exponential		von Bertalanffy parameters			
			$\log_e$ length=a=b·age	Age range (years)	L_∞	K	t_o	$\text{Log}_e(L_\infty \cdot K)$
Whitefish	North basin	1972	Y=5.335+0.132X	1-6	470.33	0.524	+0.736	5.506
		1973	Y=5.474+0.101X	1-7	522.86	0.347	+0.111	5.201
		1974	Y=5.450+0.104X	1-7	503.98	0.462	+0.772	5.450
		1975	Y=5.564+0.075X	1-9	504.907	0.403	+0.433	5.316
		1976	Y=5.535+0.071X	1-10	506.53	0.342	+0.460	5.156
		1977	Y=5.568+0.062X	1-11	501.31	0.307	+0.100	5.036
		1978	Y=5.469+0.084X	1-9	590.4	0.166	-1.318	4.584
		1979	Y=5.539+0.063X	1-11	938	0.049	-4.902	3.828
		1980	Y=5.508+0.066X	1-10	585	0.128	-2.474	4.316
		1981	Y=5.585+0.065X	1-8	471	0.284	-1.169	4.896
		1982	Y=5.564+0.058X	1-9	428	0.480	+0.811	5.325
		1983	Y=5.432+0.074X	1-9	454	0.387	+0.629	5.169
	Channel	1980	Y=5.625+0.057X	1-6	530	0.120	-5.149	4.153
		1981	Y=5.588+0.058X	1-8	445	0.429	+0.675	5.252
Walleye	South basin	1976	Y=5.228+0.171X	0-7	609	0.250	-0.782	5.026
		1977	Y=5.160+0.152X	0-8	431	0.395	-0.999	5.137
		1978	Y=5.361+0.122X	1-8	468	0.302	-1.204	4.951
		1979	Y=5.283+0.114X	1-9	460	0.326	+0.475	5.010
		1980	Y=5.019+0.150X	0-9	473	0.471	+0.889	5.406
		1981	Y=5.573+0.066X	2-9	435	0.474	-0.075	5.329
		1982	Y=5.458+0.099X	2-8	508	0.430	+0.826	5.387
		1983	Y=5.408+0.111X	2-10	667	0.195	-0.187	4.868

Species	Area	Year	Growth curve					
			Exponential		von Bertalanffy parameters			
			$\log_e$ length=a=b.age	Age range (years)	L_∞	K	t_o	$\text{Log}_e(L_\infty.K)$
	Channel	1982	Y=5.464+0.086X	3-8	567	0.218	+0.266	4.817
	North basin	1979	Y=5.049+0.073X	3-9	∞	-	-	-
		1980	Y=5.049+0.123X	1-10	500	0.248	-0.136	4.820
		1981	Y=5.170+0.120X	1-9	449	0.356	+0.042	5.074
		1982	Y=5.432+0.080X	3-10	510	0.234	+0.154	4.782
		1983	Y=5.512+0.086X	2-9	2945	-	-	-
Sauger	South basin	1976	Y=5.519+0.170X	0-5	688	0.108	-2.440	4.308
		1977	Y=5.278+0.112X	0-7	547	0.129	-2.971	4.257
		1978	Y=5.277+0.124X	1-5	578	0.120	-2.859	4.239
		1979	Y=5.218+0.097X	2-6	301	1.688	-1.445	6.231
		1980	Y=4.987+0.107X	0-10	334	0.382	-0.647	4.849
		1981	Y=5.093+0.093X	1-10	368	0.227	-1.013	4.425
		1982	Y=4.865+0.160X	1-7	390	0.375	+0.446	4.985
		1983	Y=5.200+0.112X	1-7	486	0.162	-1.934	4.366
	Channel	1979	Y=5.176+0.086X	2-8	361	0.285	+0.067	4.634
		1980	Y=5.065+0.100X	1-10	367	0.228	-1.357	4.427
		1982	Y=5.221+0.079X	1-11	495	0.147	-1.257	4.287
		1983	Y=5.289+0.093X	2-8	473	0.203	-0.953	4.565
	North basin	1979	Y=5.566+0.032X	4-14	402	0.285	+0.358	4.741
		1980	Y=5.172+0.076X	1-14	425	0.236	+0.186	4.608
		1981	Y=5.341+0.066X	1-13	415	0.280	-0.764	4.755
		1982	Y=5.154+0.084X	2-12	439	0.253	+0.622	4.710
		1983	Y=5.271+0.096X	2-9	484	0.221	-0.452	4.672

Table 13. Walford plots of walleyes, saugers and whitefish from the major areas of Lake Winnipeg, 1979-83.

Species	Area	Year	$\overline{L}_{t+1}=a+b\overline{L}_t$	$\overline{L}_\infty$ (mm)	R	Test F. ratio and d.f.
Sauger	North basin	1977	Y=1-5.526+0.738X	402	0.861	34.48(1,13)
		1980	Y=100.075+0.765X	425	0.987	254.69(1,7)
		1981	Y=130.400+0.686X	415	0.903	44.26(1,10)
		1982	Y=120.168+0.726X	439	0.968	119.32(1,8)
		1983	Y=97.358+0.799X	484	0.992	323.22(1,5)
	Channel	1979	Y=90.417+0.750X	361	0.980	145.45(1,7)
		1980	Y=73.771+0.799X	367	0.972	84.29(1,5)
		1981				
		1982	Y=61.416+0.876X	495	0.989	270.35(1,6)
		1983	Y=71.927+0.848X	473	0.977	107.09(1,5)
	South basin	1976	Y=102.399+0.787X	481	0.796	8.63(1,5)
		1977	Y=65.692+0.880X	547	0.993	380.03(1,5)
		1978	Y=67.085+0.884X	578	0.988	81.68(1,2)
		1979	Y=248.188+0.178X	301	0.826	8.57(1,5)
		1980	Y=98.822+0.706X	334	0.964	91.81(1,7)
		1981	Y=78.020+0.788X	368	0.999	4118.43(1,5)
		1982	Y=118.492+0.696X	390	0.996	351.73(1,3)
		1983	Y=73.873+0.848X	486	0.991	216.77(1,4)
Walleye	North basin	1979	Y=26.534+0.999X	∞	0.987	151.32(1,4)
		1980	Y=95.007+0.811X	500	0.951	28.13(1,3)
		1981	Y=137.280+0.694	449	0.997	643.25(1,4)
		1982	Y=120.807+0.763X	510	0.997	358.86(1,2)
		1983	Y=38.284+0.987X	∞	0.999	1699.02(1,5)

Table 13, cont'd.

Species	Area	Year	$\overline{L}_{t+1}=a+b\overline{L}_t$	$\overline{L}_\infty$ (mm)	R	Test F. ratio and d.f.
	South basin	1976	Y=120.651+0.802X	609	0.936	21.06(1,3)
		1977	Y=126.047+0.769X	546	0.918	32.02(1,6)
		1978	Y=161.948+0.654X	468	0.828	8.71(1,4)
		1979	Y=59.926+0.882X	511	0.991	228.55(1,4)
		1980	Y=158.221+0.666X	473	0.957	43.44(1,4)
		1981	Y=158.630+0.635X	435	0.982	111.03(1,4)
		1982	Y=234.282+0.539X	508	0.985	31.87(1,1)*
		1983	Y=120.136+0.820X	667	0.971	66.61(1,4
Whitefish	North basin	1972	Y=207.887+0.558X	470	0.994	78.95(1,1)*
		1973	Y=149.538+0.714X	523	0.989	43.62(1,1)*
		1974	Y=191.009+0.621X	504	0.996	365.13(1,3)
		1975	Y=174.193+0.655X	505	0.985	161.75(1,5)
		1976	Y=169.179+0.666X	507	0.995	291.48(1,3)
		1977	Y=127.333+0.746X	501	0.993	351.13(1,5)
		1978	Y=88.560+0.850X	590	0.995	409.93(1,4)
		1979	Y=52.731+0.944X	938	0.984	236.58(1,8)
		1980	Y=76.531+0.869X	585	0.986	247.17(1,7)
		1981	Y=115.980+0.754X	471	0.975	77.60(1,4)
		1982	Y=143.846+0.664X	428	0.918	26.89(1,5)
		1983	Y=112.633+0.752X	454	0.979	139.57(1,6)
	Channel	1980	Y=59.798+0.888X	530	0.997	451.74(1,3)
		1981	Y=162.965+0.643X	445	0.998	577.79(1,2)

*non significant at P=0.05.

Table 14. Relationships of $\log_e(L_\infty-\ell_t)$ and t (years) for whitefish, walleye and sauger stocks from Lake Winnipeg, 1972-83.

Species	Area	Year	$\log_e(L_\infty-\ell_t)=(\log_e L_\infty+Kt_0)-Kt$	Age range (years)	R	Test F ratio and d.f.
Whitefish	North basin	1972	$\log(470-\ell_t)=6.539-0.524t$	2-6	0.993	219.43(1,3)
		1973	$\log(523-\ell_t)=6.298-0.347t$	2-7	0.997	605.24(1,4)
		1974	$\log(504-\ell_t)=6.579-0.462t$	2-7	0.989	172.10(1,4)
		1975	$\log(505-\ell_t)=6.399-0.403t$	2-10	0.997	1330.17(1,7)
		1976	$\log(507-\ell_t)=6.385-0.342t$	2-10	0.989	313.68(1,7)
		1977	$\log(501-\ell_t)=6.248-0.307t$	2-9	0.988	252.04(1,6)
		1978	$\log(590-\ell_t)=6.162-0.166t$	2-9	0.998	1401.22(1,6)
		1979	$\log(938-\ell_t)=6.604-0.049t$	2-12	0.990	442.65(1,9)
		1980	$\log(585-\ell_t)=6.055-0.128t$	2-11	0.982	220.82(1,8)
		1981	$\log(471-\ell_t)=5.823-0.284_t$	2-8	0.996	586.61(1,5)
		1982	$\log(428-\ell_t)=6.449-0.480t$	3-8	0.994	313.69(1,4)
		1983	$\log(454-\ell_t)=6.362-0.387t$	2-9	0.988	250.66(1,6)
	Channel	1980	$\log(530-\ell_t)=5.655-0.120t$	2-7	0.999	2384.38(1,4)
		1981	$\log(445-\ell_t)=6.388-0.429t$	3-8	0.996	501.38(1,4)
Walleye	North basin	1979	unrealistic estimate of L_∞			
		1980	$\log(500-\ell_t)=6.181-0.248t$	4-8	0.970	47.70(1,3)
		1981	$\log(449-\ell_t)=6.125-0.356t$	1-8	0.996	779.01(1,6)
		1982	$\log(510-\ell_t)=6.198-0.234t$	3-9	0.990	242.82(1,5)
			unrealistic estimate of L_∞			
	South basin	1976	$\log(609-\ell_t)=6.217-0.250t$	0-7	0.984	184.94(1,6)
		1977	$\log(431-\ell_t)=5.671-0.395t$	0-6	0.989	181.07(1,4)
		1978	$\log(468-\ell_t)=5.785-0.302t$	1-4	0.962	24.96(1,2)
		1979	$\log(460-\ell_t)=5.977-0.326t$	1-7	0.964	135.46(1,5)
		1980	$\log(473-\ell_t)=6.578-0.471t$	1-8	0.963	64.57(1,5)
		1981	$\log(435-\ell_t)=6.110-0.474$	1-7	0.979	117.31(1,5)

Table 14, cont'd.

Species	Area	Year	$\log_e(L_\infty-\ell_t)=(\log_e L_\infty+Kt_0)-Kt$	Age range (years)	R	Test F ratio and d.f.
		1982	$\log(508-\ell_t)=6.586-0.430t$	1-7	0.979	77.60(1,5)
		1983	$\log(667-\ell_t)=6.467-0.195t$	2-8	0.969	252.89(1,5)
Sauger	North basin	1979	$\log(402-\ell_t)=6.099-0.285t$	4-4	0.954	125.51(1,6)
		1980	$\log(425-\ell_t)=6.096-0.236t$	1-10	0.994	527.35(1,8)
		1981	$\log(415-\ell_t)=5.815-0.280t$	2-11	0.984	239.41(1,8)
		1982	$\log(439-\ell_t)=6.241-0.253t$	2-12	0.984	266.44(1,9)
		1983	$\log(484-\ell_t)=6.083-0.221t$	2-9	0.994	514.18(1,6)
	Channel	1979	$\log(361-\ell_t)=5.867-0.324t$	2-10	0.959	163.11(1,7)
		1980	$\log(367-\ell_t)=5.596-0.228t$	1-7	0.994	389.57(1,5)
		1982	$\log(495-\ell_t)=6.020-0.147t$	1-13	0.980	270.79(1,11)
		1983	$\log(473-\ell_t)=5.966-0.203t$	2-8	0.992	293.52(1,5)
	South basin	1976	$\log(688-\ell_t)=6.270-0.108t$	0-5	0.999	1511.61(1,4)
		1977	$\log(547-\ell_t)=5.922-0.129t$	0-7	0.997	1107.09(1,6)
		1978	$\log(578-\ell_t)=6.017-0.120t$	1-5	0.997	576.71(1,3)
		1979	$\log(301-\ell_t)=3.268-1.688t$	2-5	0.974	36.93(1,2)
		1980	$\log(334-\ell_t)=5.564-0.382t$	1-9	0.986	242.37(1,7)
		1981	$\log(368-\ell_t)=5.678-0.227t$	1-9	0.992	428.59(1,7)
		1982	$\log(390-\ell_t)=6.133-0.375t$	1-9	0.976	138.23(1,7)
		1983	$\log(486-\ell_t)=5.873-0.162t$	1-7	0.998	1276.73(1,5)

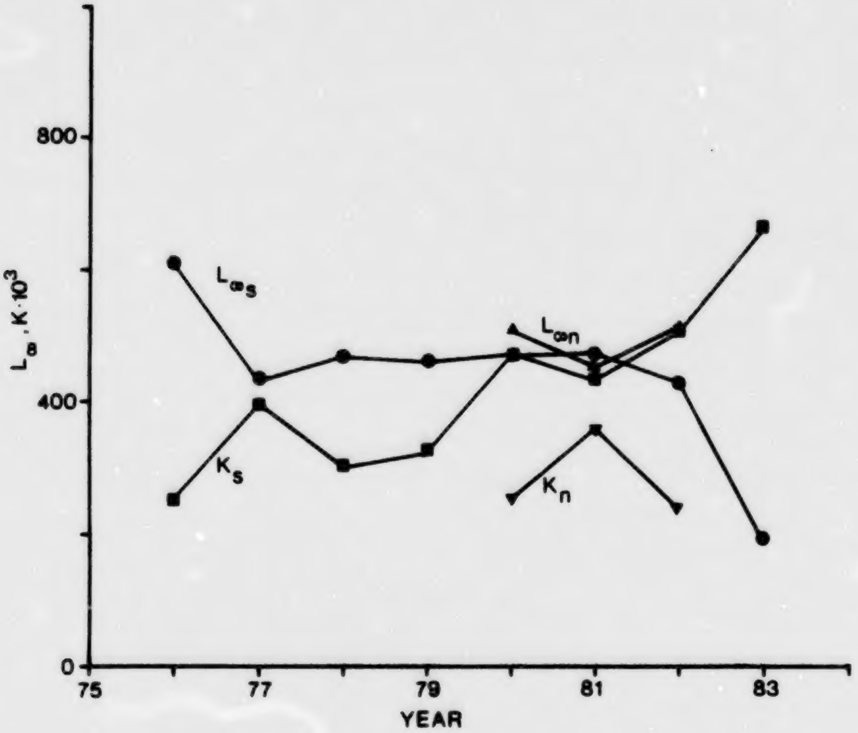


Fig. 17. Concomitant temporal changes in estimates of L_∞ and K values for northern (n) and southern (s) Lake Winnipeg walleye stocks.

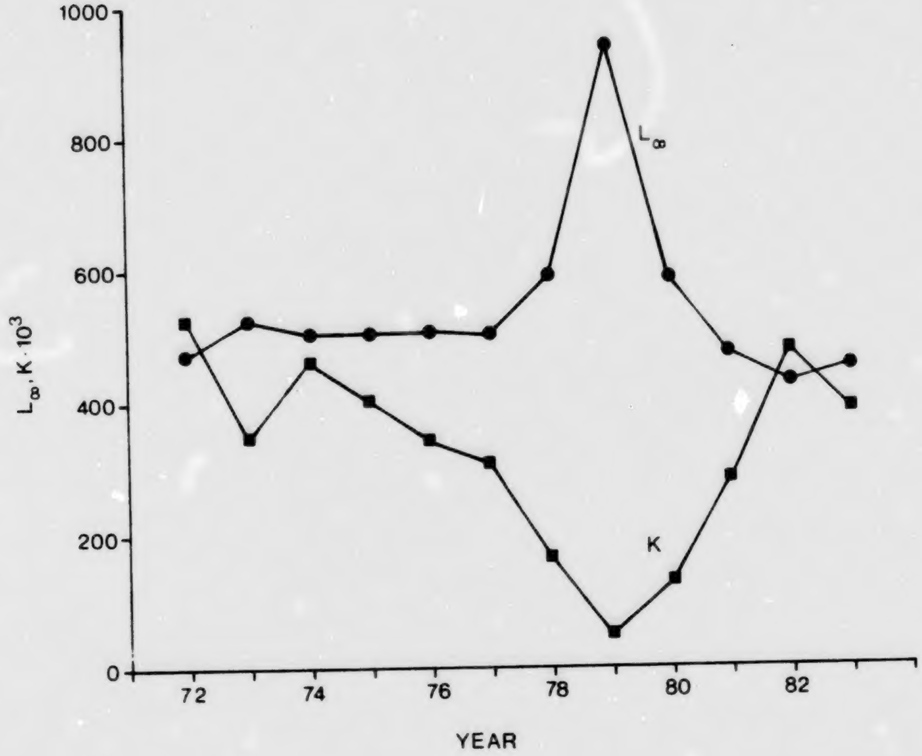


Fig. 18. Concomitant temporal changes in estimates of L_∞ and K values for the northern Lake Winnipeg whitefish stock.

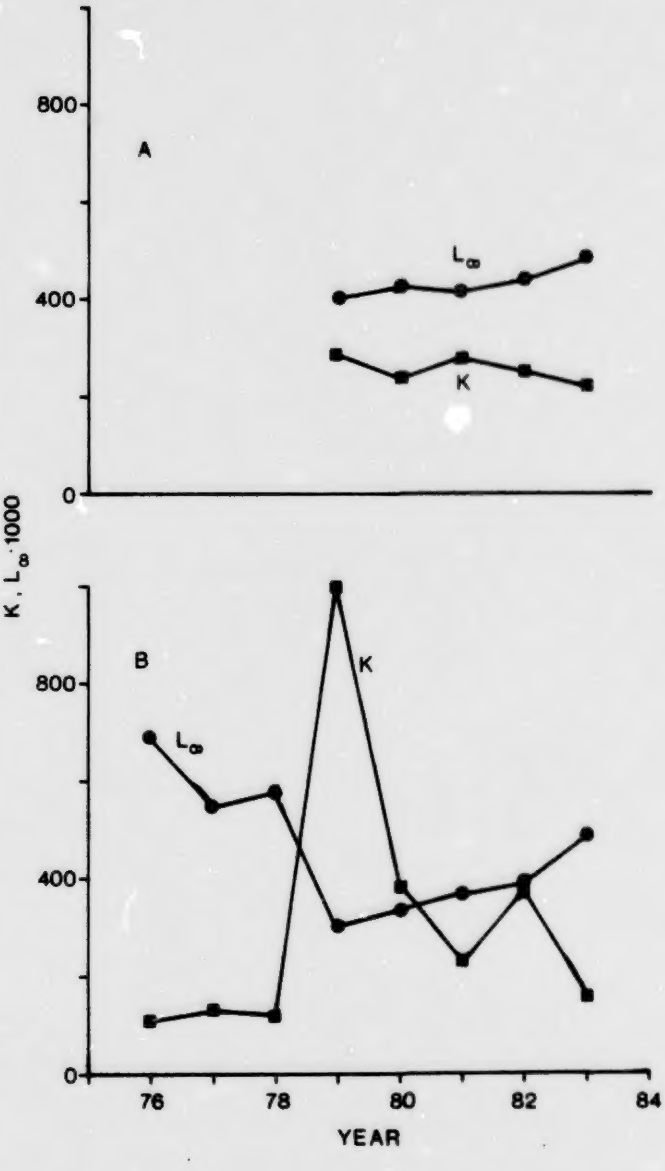


Fig. 19. Concomitant temporal changes in estimates of L_∞ and K values of northern (A) and southern (B) Lake Winnipeg sauger stocks.

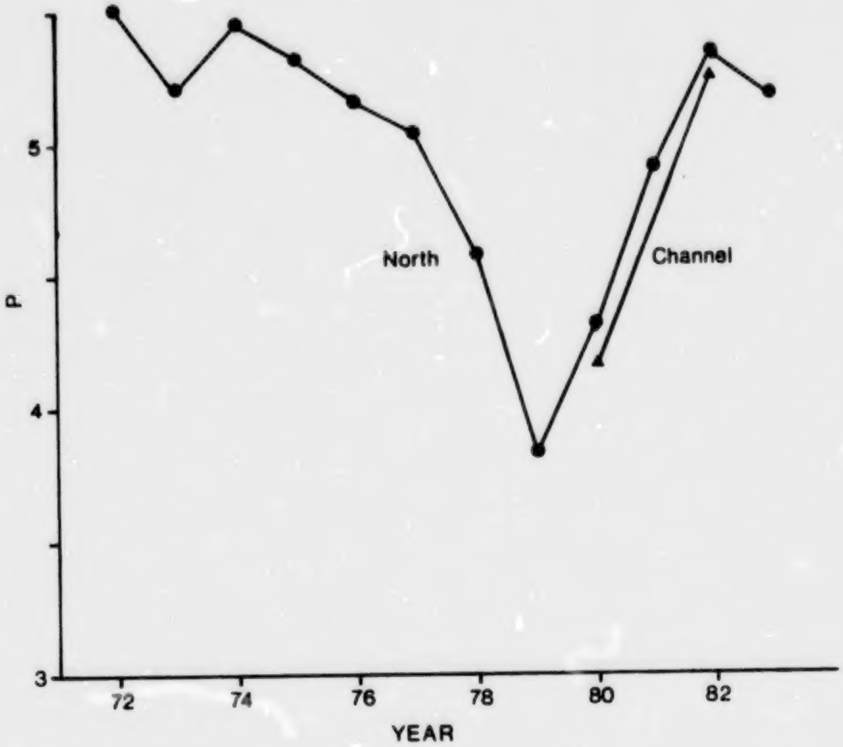


Fig. 20. Temporal changes in the Pauly statistic of northern and channel Lake Winnipeg whitefish stocks.

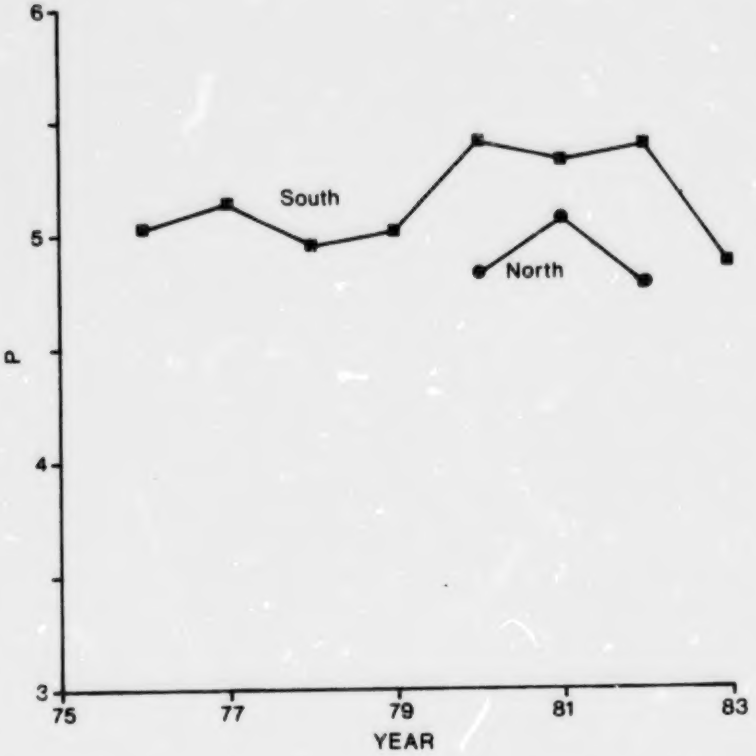


Fig. 21. Temporal changes in the Pauly statistic of northern and southern Lake Winnipeg walleye stocks.

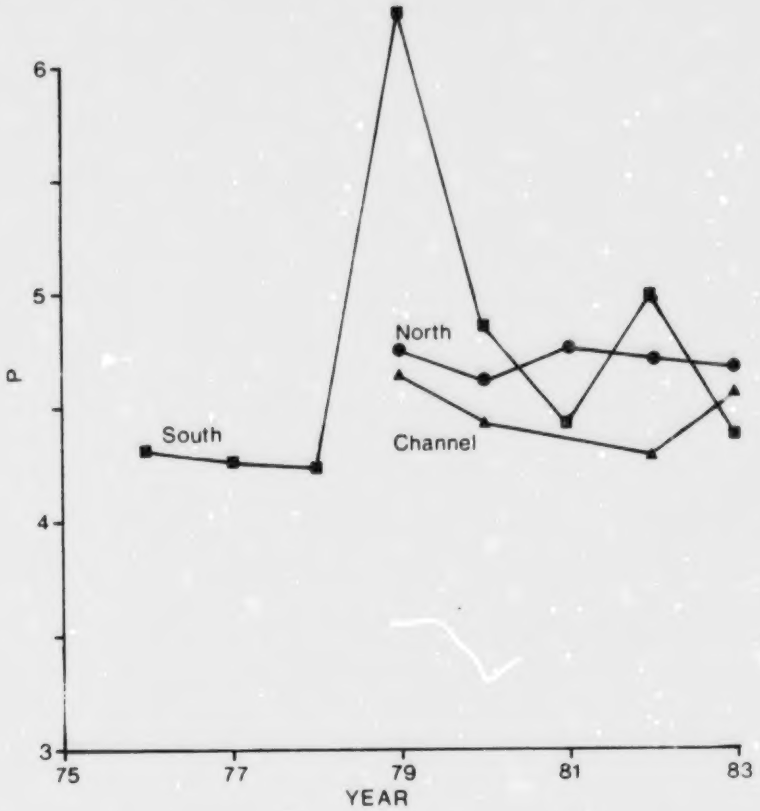


Fig. 22. Temporal changes in the Pauly statistic of northern, channel and southern Lake Winnipeg sauger stocks.

Exponential growth rates of north basin whitefish have been decreasing over a long time span (Fig. 23). In 1979, the exponential growth rate of north basin saugers were relatively slow while channel and south basin saugers displayed higher exponential growth rates. Since 1979, exponential growth rates of all three sauger stocks seem to be merging towards a common value. The temporal changes of south basin sauger growth rates are most erratic (Fig. 24). Exponential growth rates of northern and southern walleye stocks also fluctuated erractically from year to year and displayed a long term decrease (Fig. 25). The utility of the exponential growth model in describing long term changes in growth regimes is questionable since growth of Lake Winnipeg walleyes, saugers and whitefish is obviously asymptotic and since L_∞ values for each stock seem to be directly proportional to the minimum mesh sizes allowed in each area.

It is important to realize that annual estimates of growth parameters merely represent "annual cross sections" of cohort growth regimes and that more utility can be obtained by applying annual growth measurements to an analysis of cohort growth.

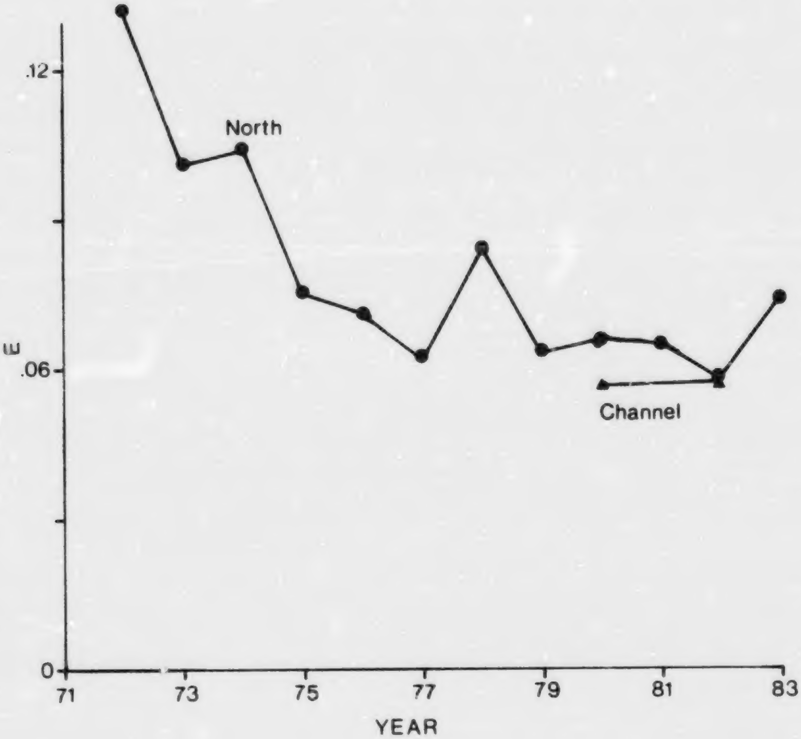


Fig. 23. Temporal changes in exponential growth rates of northern and channel Lake Winnipeg whitefish stocks.

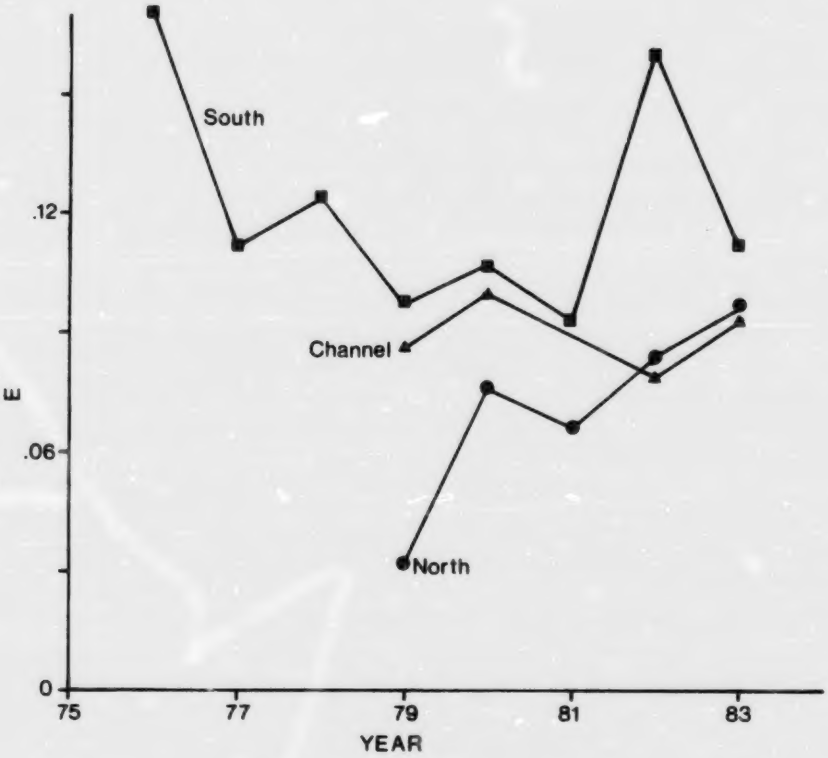


Fig. 24. Temporal changes in exponential growth rates of northern, channel and southern Lake Winnipeg sauger stocks.

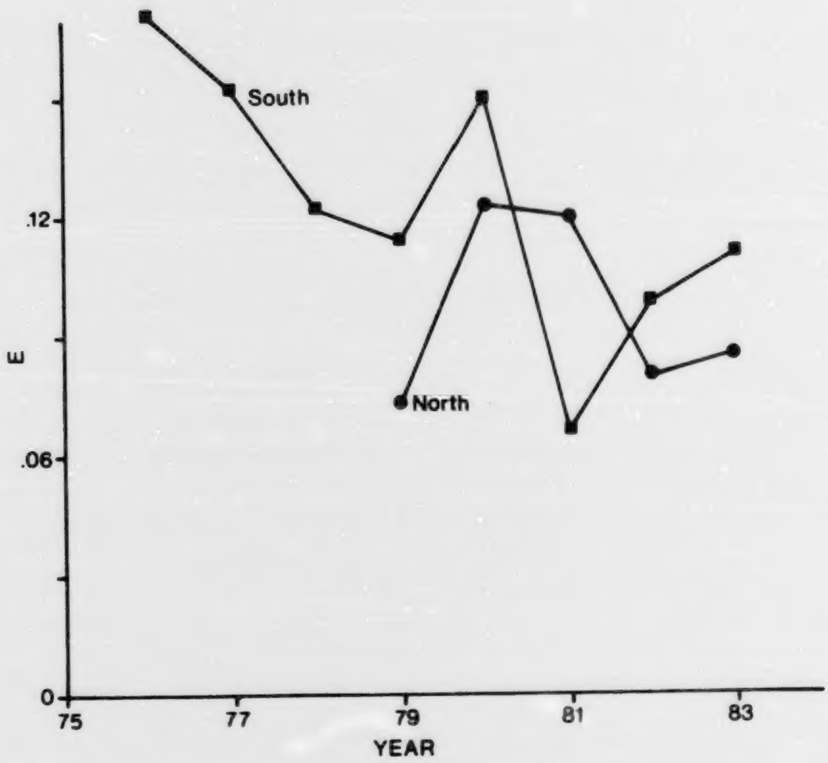


Fig. 25. Temporal changes in exponential growth rates of northern and southern Lake Winnipeg walleye stocks.

Maturity Regimes

Abrasov's estimate of the mean age of maturity

Abrasov (1967) calculated the mean weighted age of onset of sexual maturity, $\overline{A}_m$, as follows:

$$\overline{A}_m = \frac{A_1K_1 + A_2K_2 + \ldots + A_nK_n}{K_1 + K_2 + \ldots + K_n}$$

where $A_1, A_2, \ldots A_n$ are the ages of sexually mature fish.

$K_1, K_2, \ldots K_n$ are the frequencies of sexually mature fish in the nth age class.

Abrasov (1967) argued that the denominator of $\overline{A}_m$ will exceed unity since spawners in the nth age class have previously spawned. He corrected for this by equating K_n to $100-K_{n-1}$. However, this same argument can be applied to all other values of K except K_1. Thus the formula becomes:

$$\overline{A}_m = \frac{A_2K_1+A_2(K_2-K_1)+A_3(K_3-K_2)+\ldots+A_n(K_n-K_{n-1})}{K_1 + (K_2-K_1)+(K_3-K_2)+\ldots + (K_n-K_{n-1})}$$

This formula estimates the mean weighted age at which 50% of the individuals in a stock are sexually mature.

The shortcomings of Abrasov's formula are:

1. it merely provides estimates of one parameter in a regime where other parameters (such as maturity rates) have important descriptive value.
2. the estimate of $\bar{A}_m$ provided by the formula depends on gear selectivity.

Annual descriptions of maturity regimes

The use of the logistic model in annual descriptions of age or size specific frequencies of mature fish offers the following advantages:

1. estimates of maturity parameters are not dependent on changes in gear selectivity
2. maturity rates as well as $\bar{A}_m$ values can be obtained
3. spatial and/or temporal changes in maturity curve rates and elevations may be analysed using covariance analysis.

Annual estimates of $\bar{A}_m$ and instantaneous maturity rates of female walleyes, saugers and whitefish (Table 15) were used in least squares regressions to describe and compare their long term temporal changes (Table 16). Annual estimates of $\bar{A}_m$ of northern whitefish remained relatively static while maturity rates increased erratically from 1979-1983 (Fig. 26). $\bar{A}_m$ estimates for saugers did not change significantly from 1979-1983 and were not spatially discrete. Maturity rates of both northern and southern sauger stocks tended to increase over

Table 15. Maturity curves of female walleyes, saugers and whitefish from major areas of Lake Winnipeg, 1979-83.

Species	Lake area	Year	Maturity curve $-\log_e\frac{(K-Y)}{Y}=bX_o+bX$	Age at 50% mature (years)	Correlation coefficient	Test F ratio and d.f.
	North	1979	Y=-7.43+1.07X	6.92	0.970	64.02(1,4)
		1980	Y=-11.00+1.46X	7.55	0.895	12.07(1,3)
		1981	Y=-6.642+0.904X	7.34	0.975	58.75(1,3)
		1982		sample size too small		
		1983	Y=-11.869+1.551X	7.65	0.956	21.49(1,2)
	South	1979	Y=-5.43+0.720X	7.54	0.948	35.25(1,4)
		1980	Y=-5.896+1.100X	5.36	0.968	29.92(1,2)
		1981	Y=-9.977+1.891X	5.28	0.997	291.49(1,2)
		1982	Y=-10.913+1.942X	5.62	0.985	66.07(1,2)
		1983	Y=-9.315+1.706X	5.46	0.989	45.06(1,1)*
Sauger	North	1979	Y=-3.960+1.022X	3.87	0.991	109.07(1,2)
		1980	Y=-5.874+1.101X	5.34	0.973	71.33(1,4)
		1981	Y=-3.309+0.776X	4.26	0.977	82.52(1,4)
		1982	Y=-8.009+1.422X	5.63	0.970	31.53(1,2)
		1983	Y=-8.417+2.188X	3.85	0.997	186.30(1,1)
	South	1979	Y=-3.52+1.37X	2.57	0.956	10.70(1,1)*
		1980	Y=-5.427+1.462X	3.71	0.956	21.11(1,2)
		1981	Y=-8.351+1.724X	4.82	0.985	100.24(1,3)
		1982	Y=-8.846+1.740X	5.08	0.937	14.34(1,2)*
		1983	Y=-8.671+2.249X	3.86	0.977	21.38(1,1)*

Table 15, cont'd.

Species	Lake area	Year	Maturity curve $-\log_e\frac{(K-Y)}{Y}=bX_o+bX$	Age at 50% mature (years)	Correlation coefficient	Test F ratio and d.f.
Whitefish	North	1979	Y=-4.37+1.12X	3.90	0.959	34.46(1,3)
		1980	Y=-6.399+1.081X	5.92	0.952	48.70(1,5)
		1981	Y=-4.802+0.950X	5.05	0.868	9.19(1,3)*
		1982	Y=-10.417+2.214X	4.71	0.998	212.11(1,1)
		1983	Y=-10.862+1.948X	5.58	0.993	137.04(1,2)
	Channel	1982	Y=06.914+1.574X	4.39	0.971	32.78(1,2)

* non-significant at P=0.05.

Table 16. Temporal regressions of maturity rates and $\overline{A}_m$.

Species	Lake area	Regression equation $Y=a+b.X$*	R	Test F value	d.f.
Whitefish	North	$\overline{A}_m=-12.383+0.215X$	0.432	0.69	1,3
	basin	$Rate=-21.128+0.279X$	0.766	4.26	1,3
Sauger	North	$\overline{A}_m=2.565+0.025X$	0.047	0.01	1,3
	basin	$Rate=-20.056+0.265X^{a.}$	0.910	9.68	1,2
	South	$\overline{A}_m=-27.987+0.395X$	0.626	1.93	1,3
	basin	$Rate=-14.783+0.204X$	0.940	22.95†	1,3
Walleye	North	$\overline{A}_m=-4.401+0.146X$	0.769	2.90	1,2
	basin	$Rate=-6.666+0.099X^{b.}$	0.811	1.92	1,1
	South	$\overline{A}_m=-0.214+0.064X^{c.}$	0.564	0.93	1,2
	basin	$Rate=-21.322+0.281X$	0.828	6.54	1,3

* X=time (years)

† significant at P=0.05

a. 1981 outlier datum was deleted (see Fig. 27)

b. 1981 outlier datum was deleted (see Fig. 28)

c. 1981 outlier datum was deleted (see Fig. 28).

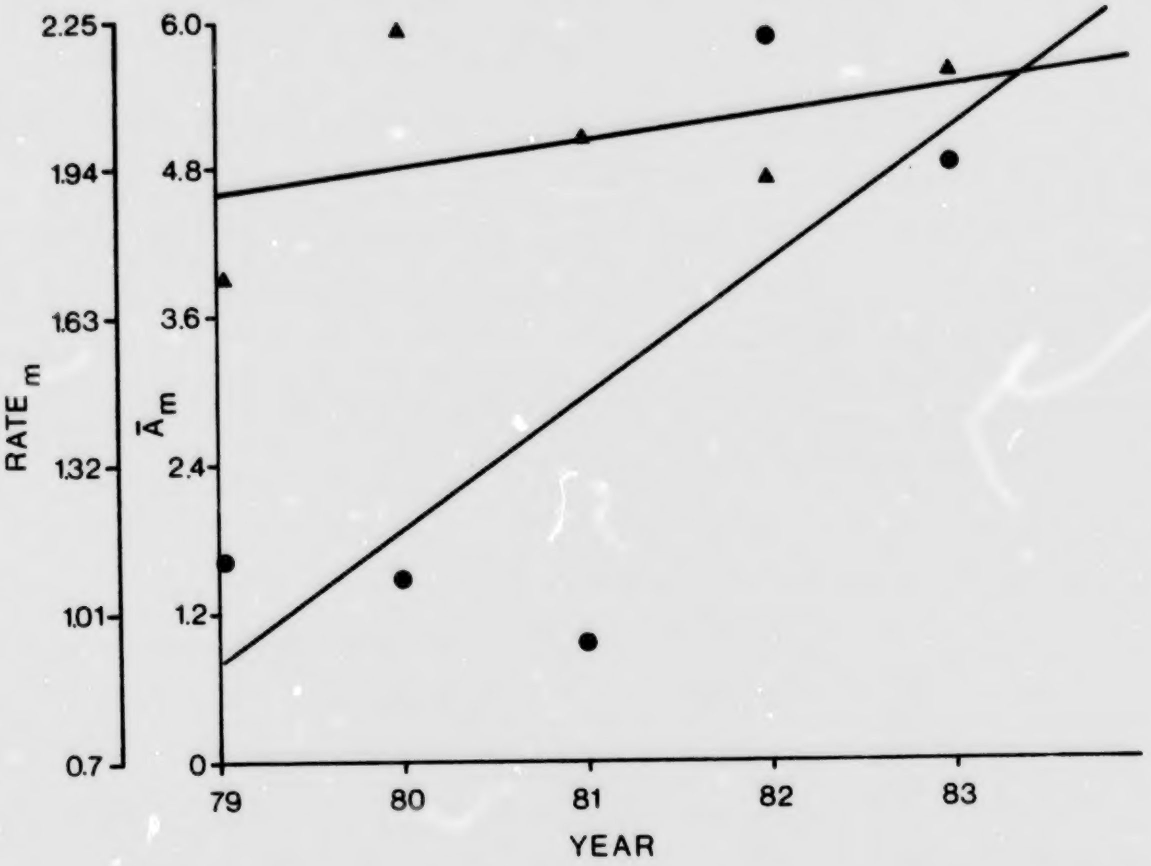


Fig. 26. Temporal changes in mean ages of maturity, $\bar{A}_m$ (▲) and instantaneous maturity rates (●) of the north basin whitefish stock.

time and displayed more spatial segregation (Fig. 27, Table 16). $\bar{A}_m$ estimates for northern and southern walleye stocks remained constant and were consistently lower for southern walleyes. Maturity rates of southern walleyes tended to increase faster and less erratically than those of northern walleyes (Fig. 28). Temporal changes in $\bar{A}_m$ and maturity rates were statistically insignificant in all cases except for the maturity rate change for southern saugers (Table 16). This was expected since the time interval (1979-1983) was rather short. In general it seems that $\bar{A}_m$ tends to remain relatively constant while maturity rates tend to increase faster over the long term.

Relationships of maturity and growth regimes

Since changes in maturity rates seemed to exhibit more discernable spatial and temporal patterns, their relation to changes in growth parameters was examined using least squares regression. It was hypothesized that long term changes in maturity and growth rates should be positively correlated since both growth and maturity exhibit compensatory increases in response to increasing exploitation. Most of the correlations relating maturity rates to exponential growth rates or P values were not significant except for the relation of maturity rates and exponential growth rates of north basin saugers (Table 17).

The analyses listed on Table 17 failed to reveal significant relationships between rates of growth and maturity in most cases because

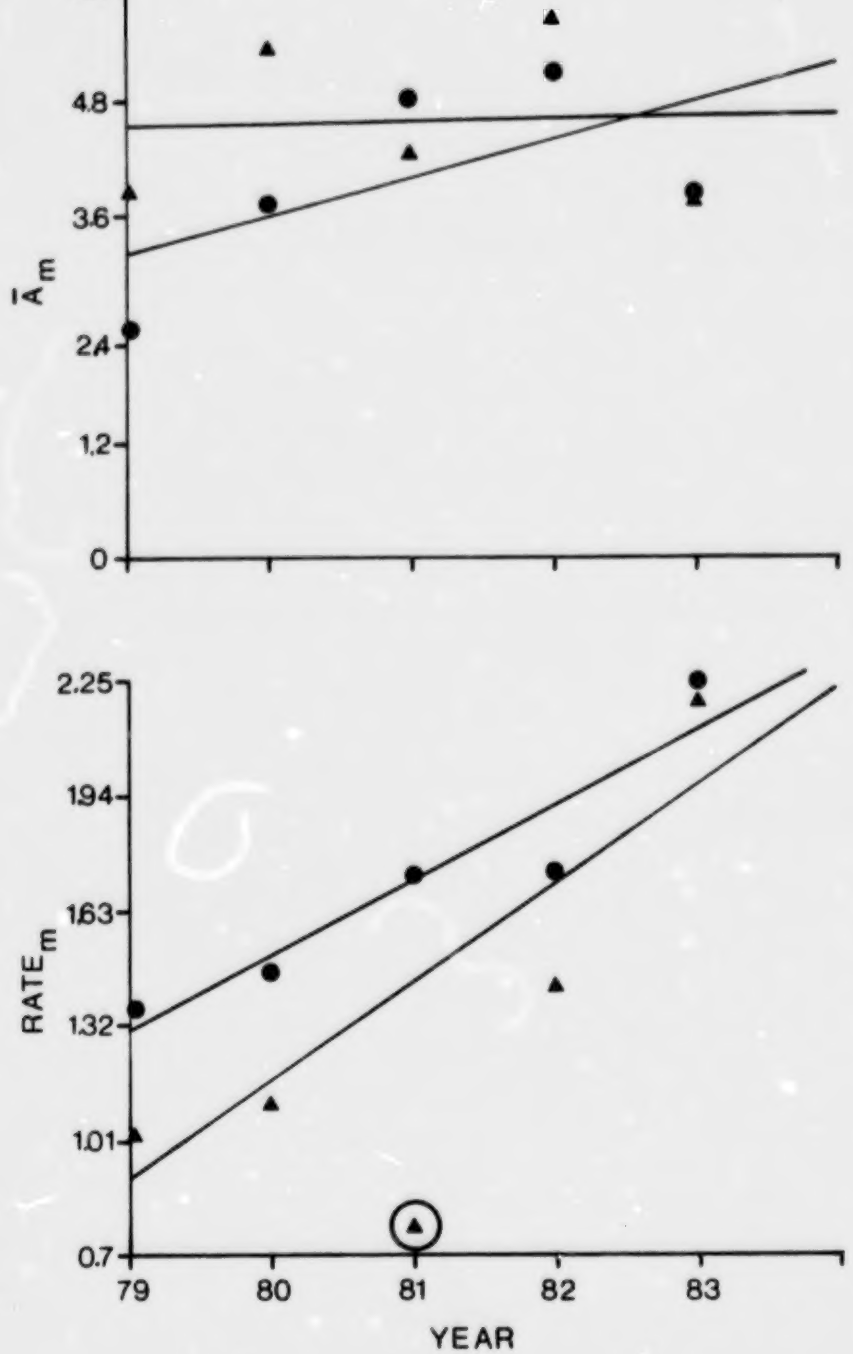


Fig. 27. Temporal changes in mean ages of maturity ($\bar{A}_m$) and instantaneous maturity rates of north basin (▲) and south basin (●) sauger stocks. Circled datum was deleted from analysis.

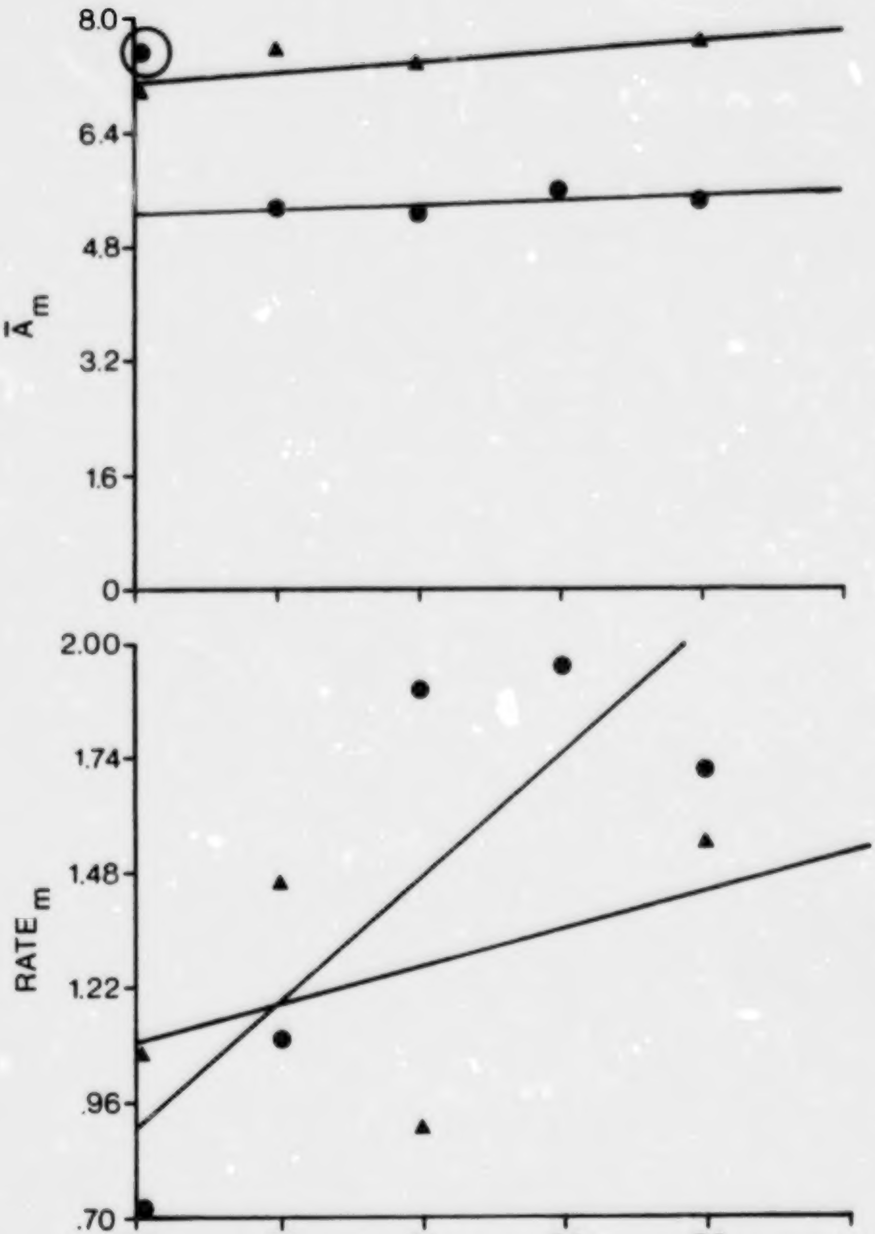


Fig. 28. Temporal changes in mean ages of maturity ($\bar{A}_m$) and instantaneous maturity rates of north basin (▲) and south basin (●) walleye stocks. Circled datum was deleted from analysis.

Table 17. Relationships of instantaneous maturity rates and the growth parameters of Lake Winnipeg stocks.

Species	Lake	Correlations					
		Exponential growth rate			P		
		Y=a+b.X[a.]	R	Test F. value and d.f.	Y=a+b.X[b.]	R	Test F value and d.f.
Sauger	North basin	Y=-2.409+46.966X	0.985	67.40(1,2)	Y=16.561-3.249X	0.352	0.42(1,3)
	South basin	Y=-0.839+24.844X	0.552	0.88(1,2)	Y= 3.313-0.323X	0.710	3.04(1,3)
Walleye	North basin	Y= 1.323-0.767X	0.062	0.01(1,2)	insufficient data		
	South basin	Y= 2.691-11.292X	0.635	2.03(1,3)	Y=-1.351+0.543X	0.248	0.20(1,3)
Whitefish	North basin	Y= 1.747-4.359X	0.044	0.01(1,3)	Y=-1.688+0.669X	0.725	3.33(1,3)

a. Y= instantaneous maturity rate, X = exponential growth rate

b. Y= instantaneous maturity rate, X = P = $\log_e(L_\infty.K)$

c. significant at P=0.05, 1979 outlier datum, deleted.

the data covered a relatively short time span. Also, minor variations in annual estimates of each parameter produce major anomalies when one attempts to describe their relationships (Figs. 29-31).

Survival Regimes

Annual survival estimates

The age compositions annually determined by experimental netting of walleye, sauger and whitefish stocks (Figs. 32-36) were converted to catch curves which provided estimates of annual survival rates (Table 18). Survival rates determined prior to 1979 were omitted because the ages of older fish tended to be underestimated during this time (Figs. 11-16). Annual sample sizes of walleyes and whitefish netted in the channel area were too small to derive reliable survival estimates during most years (Table 18).

Robson and Chapman (1961) and regression estimates of instantaneous mortality, Z, annual mortality, A, and survival, S, rates are listed in the annual stock assessment reports (Lysack 1980-84). In many cases especially when age compositions were irregular, Robson-Chapman estimates of Z, A and S relied only on the last two age class frequencies. Values of S listed on Table 18 were determined by regression analyses of the descending limbs of catch curves. During some years, regression estimates of Z included analysis of the peak point of

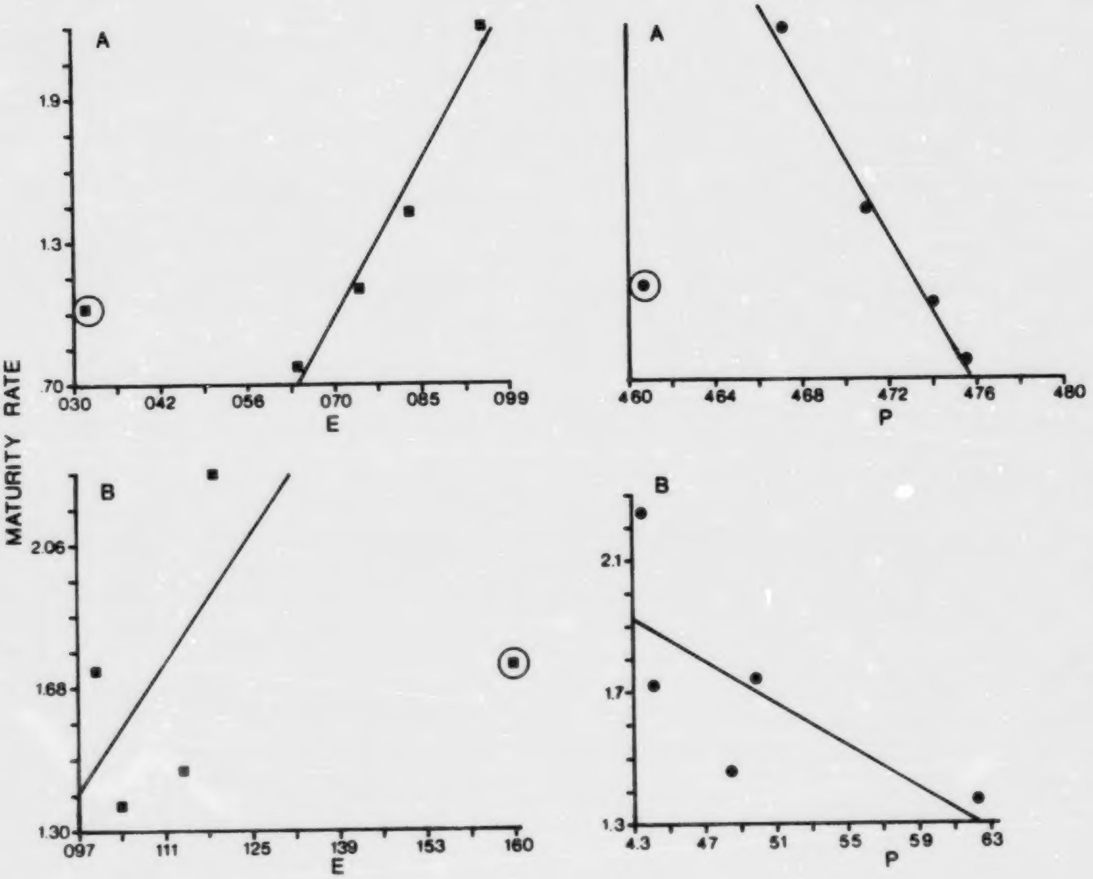


Fig. 29. Relationships of instantaneous maturity rates to exponential growth rates, E, and Pauly statistics, P, of north basin (A) and south basin (B) sauger stocks. Circled points were omitted from regression analysis.

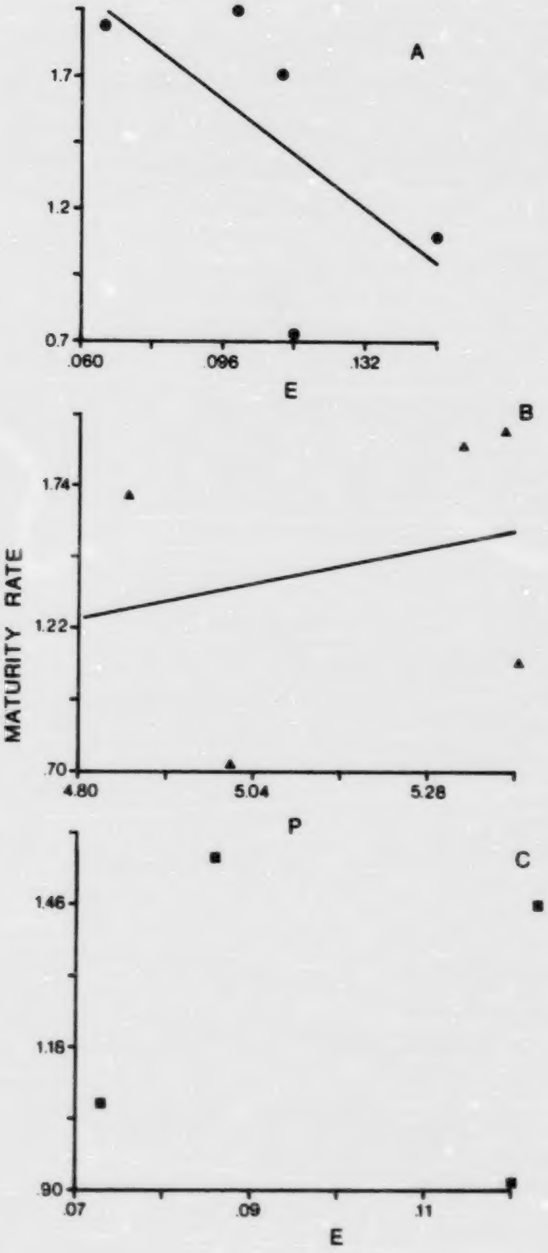


Fig. 30. Relationship of instantaneous maturity rate to: exponential growth rate, E, of south basin walleyes (A), Pauley statistic, P, of south basin walleyes (B) and exponential growth rate of north basin walleyes (C).

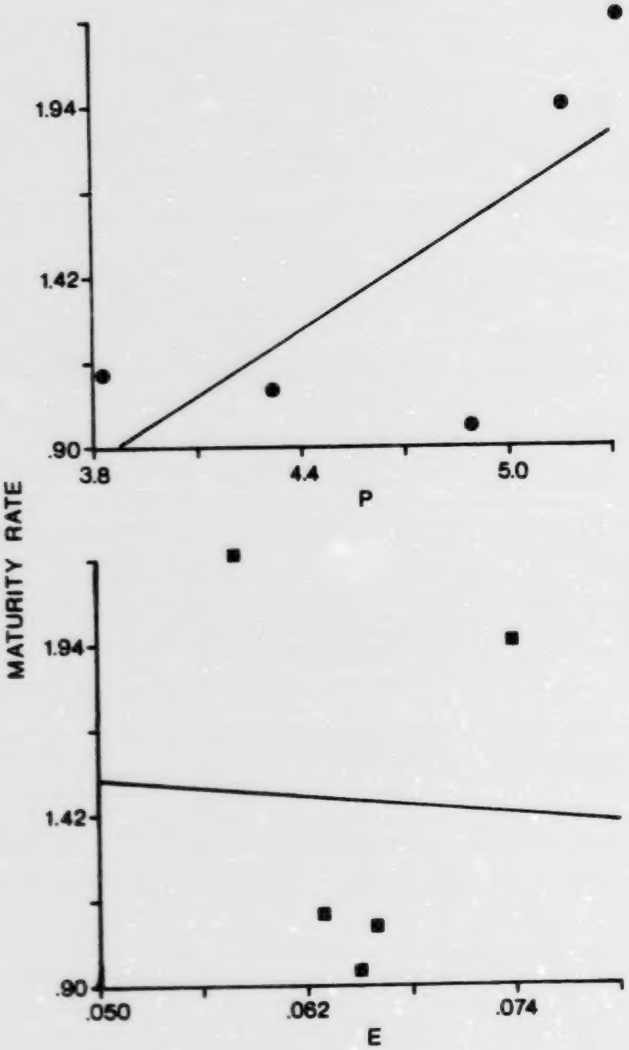


Fig. 31. Relationship of instantaneous maturity rate the Pauley statistic, P, and exponential growth rate of north basin whitefish.

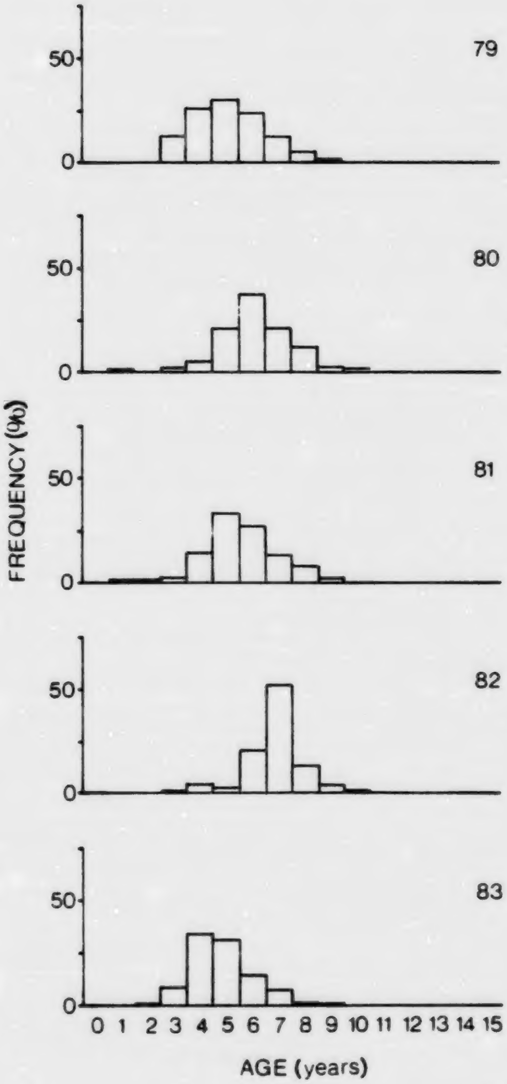


Fig. 32. Annual north basin walleye age compositions determined by experimental gillnetting.

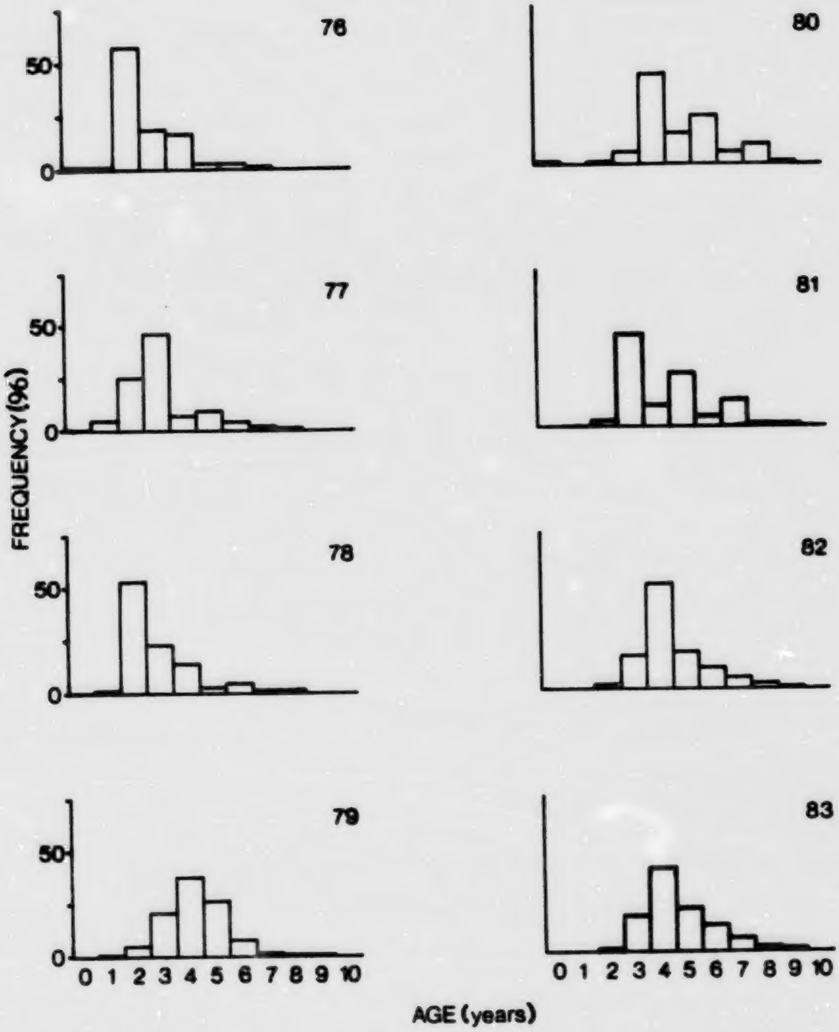


Fig. 33. Annual south basin walleye age compositions determined by experimental gillnetting.

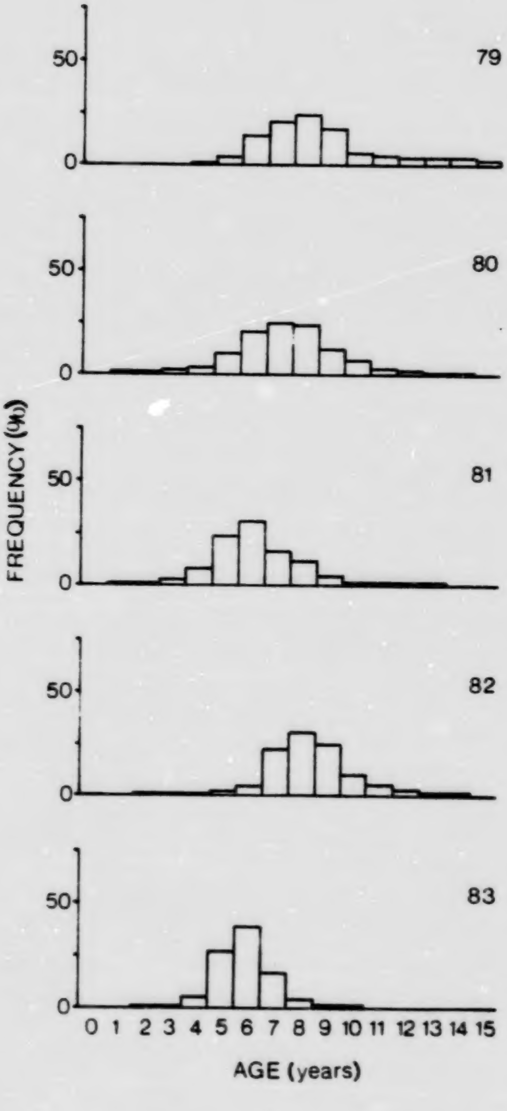


Fig. 34. Annual north basin sauger age compositions determined by experimental gillnetting.

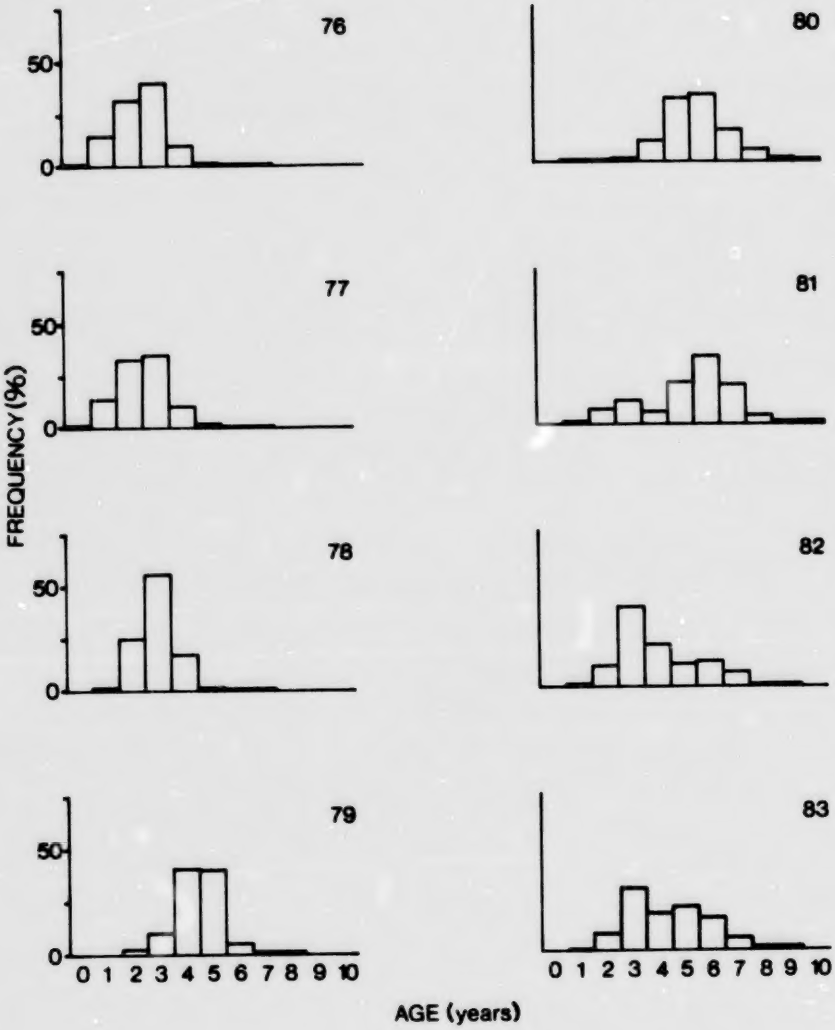


Fig. 35. Annual south basin sauger age compositions determined by experimental gillnetting.

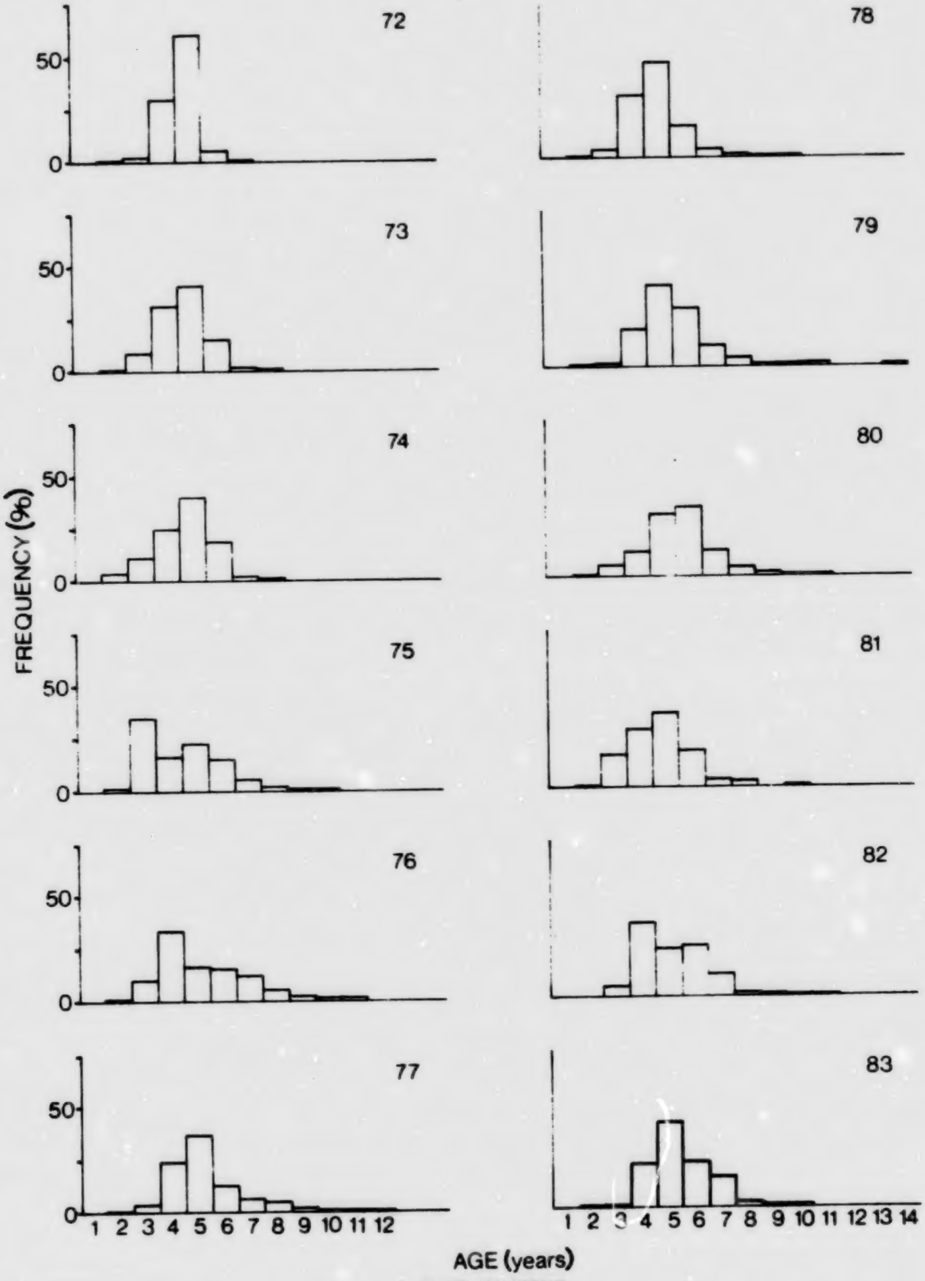


Fig. 36. Annual north basin whitefish age compositions determined by experimental gillnetting.

Table 18. Annual survival rates of walleye, sauger and whitefish stocks from the three major areas of Lake Winnipeg.

Species	Year	Annual survival rates								
		Experimental netting			Commercial sampling					
					Summer			Fall		
		North basin	Channel	South basin	North basin	Channel	South basin	North basin	Channel	South basin
Walleye	1979	.482	-	.301	.2671	.5945	.5543	.3606	.5827	.4317
	1980	.2923	-	.6505	.3291	-	.3434	-	.1826	.4430
	1981	.3844	-	.2917		.3406-.3668	.4471	-	.2531-.5326	.2671-.3848
	1982	.3015	.3538	.4863	.1324	.3485	.5143	.1936	.2888	.4102
	1983	.3646	-	.4498	.1094	-	.5231	.3376	.3135-.4300	.4037
Sauger	1979	.684	.566	.109	.3985	.2122	.4677	.2060	.1738	.0503
	1980	.4868	.2923	.3642	-	.2885	.3199	-	.3082	.1020
	1981	.3761	-	.1505	-	.2734	.0727-.2405	-	.2295	.1336-2209
	1982	.3860	.3620	.2163	-	.4025	.2112	-	.1785	.2386
	1983	.1869	.3772	.2856	-	.2747	.1967	-	.3440	.0994
Whitefish	1979	.336	-	-	.4404	.5169	-	-	.3104	-
	1980	.3867	.7334	-	.3024	-	-	-	.1674	-
	1981	.2334	-	-	.2706	.1524	-	-	-	-
	1982	.3113	.2605	-	.1049	.4426	-	-	-	-
	1983	.2666	-	-	.1087	-	-			

the catch curve because only two points occurred beyond the peak.

Parallel spatial and temporal trends between experimental and commercial S values are not evident for any stock (Table 18).

Differences in general characteristics of the age compositions between northern and southern walleye (Figs. 32,33) sauger (Figs. 34,35) stocks are:

a. The modal ages of northern stocks of both species are older than those of southern stock.
b. Two or three age classes are dominant in the northern age compositions while one or two age classes are dominant in the southern age compositions
c. The northern age compositions are not characterized by irregularly fluctuating age class frequencies
d. Wider age ranges of saugers occur in the northern basin than in the south basin. Ages of northern and southern walleye stocks cover a common range.
e. Proportions of two and three year old walleyes and saugers are higher in southern stocks.

In contrast, the age compositions of the northern whitefish stock remained relatively stable (in terms of modal age, age range, shape) from 1972 to 1983. (Fig. 36).

Irregular fluctuations and the predominance of strong age classes in the age compositions of all three species caused the right limbs of catch curves to decline in a nonlinear fashion. This implies that the assumptions about estimating survival rates (Ricker 1975) are violated and more importantly, implies that recruitment of walleye, sauger and whitefish cohorts varies from year to year. Ricker (1975) encouraged collecting catch per unit of fishing effort, CUE, data for the youngest age groups and following separate cohorts throughout their lifespan in order to describe variations in recruitment and facilitate interpretation of catch curves.

Temporal changes in trawl catches of juvenile walleyes and saugers

Kristofferson (1985) conducted a trawling program on southern Lake Winnipeg from 1976-83. He combined CUE data from the south basin and southern channel areas for juvenile (0-2 years old) walleyes and for juvenile (0-2 years old) saugers and treated data from the northern channel area separately. Walleye and sauger CUE (age specific number of fish per trawl) data from the three areas defined by Kristofferson (1985) are listed on Table 19. CUE data from 48 autumal trawls collected in 1979 were excluded from anlaysis by Kristofferson (1985, see Tables 5,9). These data are included in Table 19.

Since incurrent rivers influence many limnological parameters in Lake Winnipeg, it was hypothesized that year-to-year changes in CUE of young of the year, YOY, walleyes and saugers might be related to vernal flows of major incurrent rivers and vernal thermal regimes of Lake

Table 19. Mean numbers of young walleyes and saugers caught per trawl in three areas of Lake Winnipeg, 1976-83.

Area	Year	No. trawls	CUE (mean no. fish trawl^{-1})							
			Walleye				Sauger			
			0+	1+	2+	Total	0+	1+	2+	Total
South Basin	1976	101	3.2673	0.0891	0	3.3564	0.8713	0.9604	0.0297	1.8614
	1977	147	0.1361	0.2653	0	0.4014	0.0340	0.1020	0.5578	0.6939
	1978	159	8.0566	0.1384	0.0377	8.2327	1.7799	0.0126	0.0377	1.8301
	1979	95	2.5789	0.2842	0.0105	2.8737	8.0632	0.1474	0	8.2105
	1980	87	0.4253	0.2069	0.1724	0.8046	0.1034	0.8161	0.1609	1.0805
	1981	135	0.3185	0.0296	0.0148	0.3630	0.3778	0.0889	0.4667	0.9333
	1982	136	1.0074	0.0662	0.0221	1.0956	0.8015	0.7500	0.2206	1.7721
	1983	100	2.7000	0.0900	0.0100	2.8000	0.4200	0.0200	0.1300	0.5700
South Channel	1976	48	2.7500	0.1042	0	2.8542	1.1250	1.000	0	2.1250
	1977	48	0.2708	0.1042	0	0.3750	0.3542	0.0625	0.1250	0.5417
	1978	76	16.5526	0.0658	0	16.6184	3.2763	0.0263	0.0395	3.3421
	1979	40	6.8000	0.1500	0	6.9500	2.3500	0.0250	0	2.3750
	1980	24	0.2917	0.0147	0	0.3333	0.3750	0.1250	0	0.5000
	1981	50	1.1400	0.0800	0	1.2200	4.0400	0.2200	0.4200	4.6800
	1982	81	1.0370	0.0741	0.0123	1.1235	0.1605	1.4198	0.2716	1.8519
	1983	100	1.9800	0.2200	0.0100	2.2100	0.4900	0.0400	0.3000	0.8300
North Channel*	1978	87	1.6322	0.0575	0.0230	1.7126	15.7000	0.0805	0.1609	15.9425
	1980	97	0.1134	0.1649	0.0412	0.3196	1.4330	0.6495	0.0515	2.1340
	1981	56	0.0714	0.0536	0	0.1250	1.3571	0.0357	0	1.3929
	1982	70	0	0.1286	0	0.1286	0	4.000	0.0857	4.0857
	1983	100	0.3100	0.3400	0	0.6500	3.4000	0.5100	0.2000	4.1100

*not sampled in 1976, 1977, 1979.

Winnipeg waters. Least squares regession analyses of daily water temperatures measured from spring breakup (May) to the end of June each year from 1972-82 provided estimates of Lake Winnipeg water warming rates (Table 20). Mean May flow rates of incurrent rivers were provided in the Manitoba historical streamflow summaries (Water Resources Branch, Environment Canada).

Multiple regression (MLR) analyses of CUE values as a function of warming rates and flow rates of incurrent rivers were performed for walleyes and for saugers in each area listed in Table 21. The rationale for constructing the area-specific MLRs is as follows:

a. South basin - the Red, Winnipeg and Brokenhead Rivers empty into the south basin of Lake Winnipeg. The Manigotagan River enters Lake Winnipeg near the northern boundary of the south basin as defined by Kristofferson (1985). Thus the flow rates of the Manigotagan River were included in both the south basin and channel analyses (Table 21).

b. South channel - the Fisher and Icelandic Rivers drain into the south channel area while the Manigotagan, Bloodvein, Pigeon and Berens Rivers empty into eastern Lake Winnipeg. The Bloodvein River was not included in the MLR because its flow rate data were not recorded from 1972-75. The Icelandic River was omitted since it is a relatively

Table 20. Vernal warming rates of Lake Winnipeg surface water recorded at Gimli, 1972-1982.

Year	Temporal warming function*	R	Test F value and d.f.
1972	Y = 2.897 + 0.288X	0.890	190.64(1,50)
1973	Y = 8.154 + 0.178X	0.852	119.54(1,45)
1974	Y = 0.455 + 0.309X	0.914	176.50(1,35)
1975	Y = 2.377 + 0.304X	0.970	698.58(1,44)
1976	Y = 5.051 + 0.256X	0.905	261.69(1,58)
1977	Y = 6.774 + 0.249X	0.857	144.28(1,52)
1978	Y = 5.304 + 0.227X	0.918	251.95(1,47)
1979	Y = 2.061 + 0.319X	0.919	152.33(1,28)
1980	Y = 5.980 + 0.239X	0.894	201.93(1,51)
1981	Y = 6.586 + 0.198X	0.899	213.74(1,51)
1982	Y = 7.999 + 0.163X	0.912	187.15(1,38)

*Y = daily surface water temperature (°C), X = time (days).

small river that empties into a shallow, marshy area northeasterly by Hecla Island. The warming rate estimates were common in all three area - specific MLRs since daily water temperature data were recorded only at Gimli from 1972-82.

c. North and south channel (pooled) - these data were pooled in an attempt to account for the 1976, 1977 and 1979 voids in the north channel data series and to provide a MLR for the general channel area.

The MLRs listed in Appendix A were derived from the 1976-83 data and were used to estimate the 1972-75 CUE values for walleyes and saugers (Table 21, Figs. 37-42). In the south basin relatively strong walleye cohorts were observed in 1976, 1978, 1979 and 1983 (Fig. 37). The strengths of the 1978 and 1979 walleye cohorts were more evident in the channel (Figs. 38,39) than in the south basin.

A major discrepancy in relative strengths of sauger cohorts occurred between the south basin and channel areas. In the south basin, the 1979 and 1982 sauger cohorts were relatively strong (Fig. 40) while the 1978 and 1981 cohorts were strong in the channel (Figs. 41,42).

Simple correlations of walleye and sauger CUE values and warming rates and flow rates were all higher in the pooled north and south channel area than in the south channel area (Appendix A).

The MLR models predicted that the strongest cohorts of both

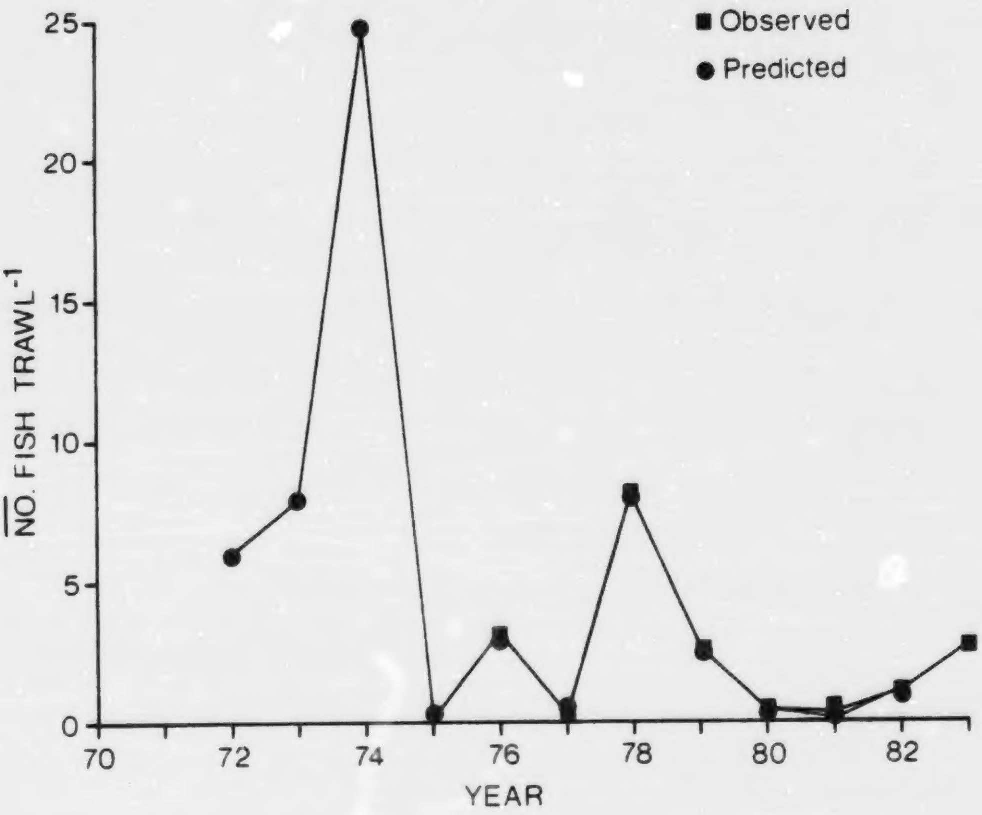


Fig. 37. Observed and predicted CUE (mean no. fish trawl^{-1}) values for south basin walleyes.

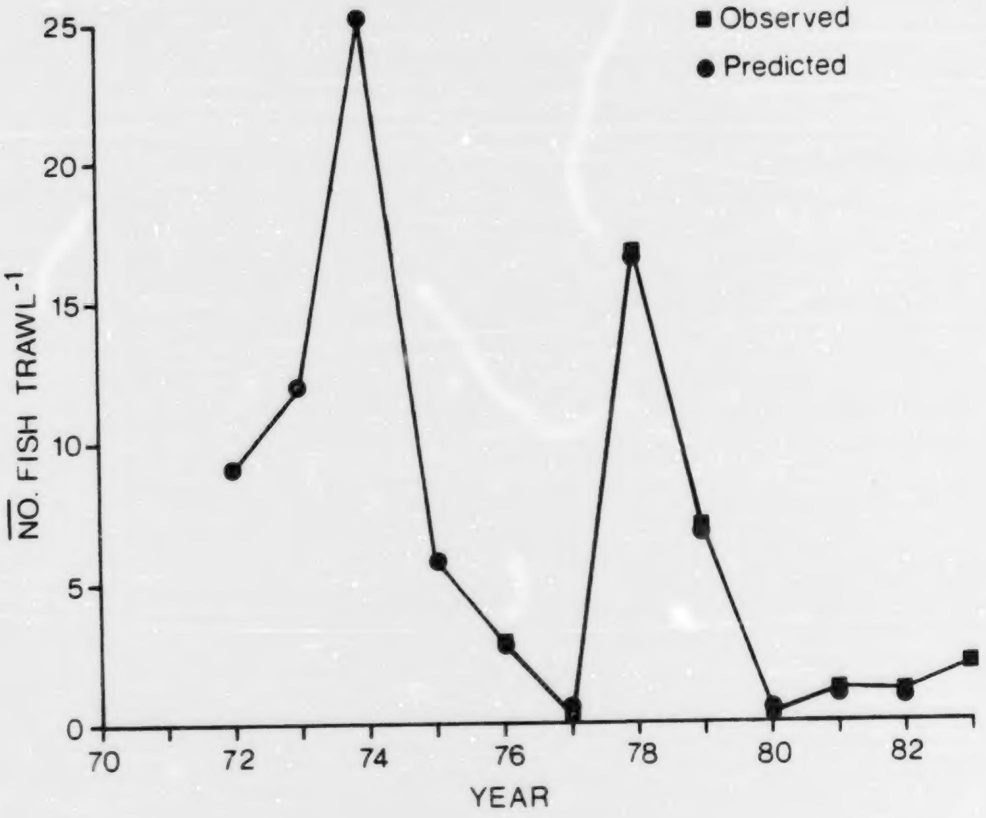


Fig. 38. Observed and predicted CUE (mean no. fish trawl^{-1}) values for south channel walleyes.

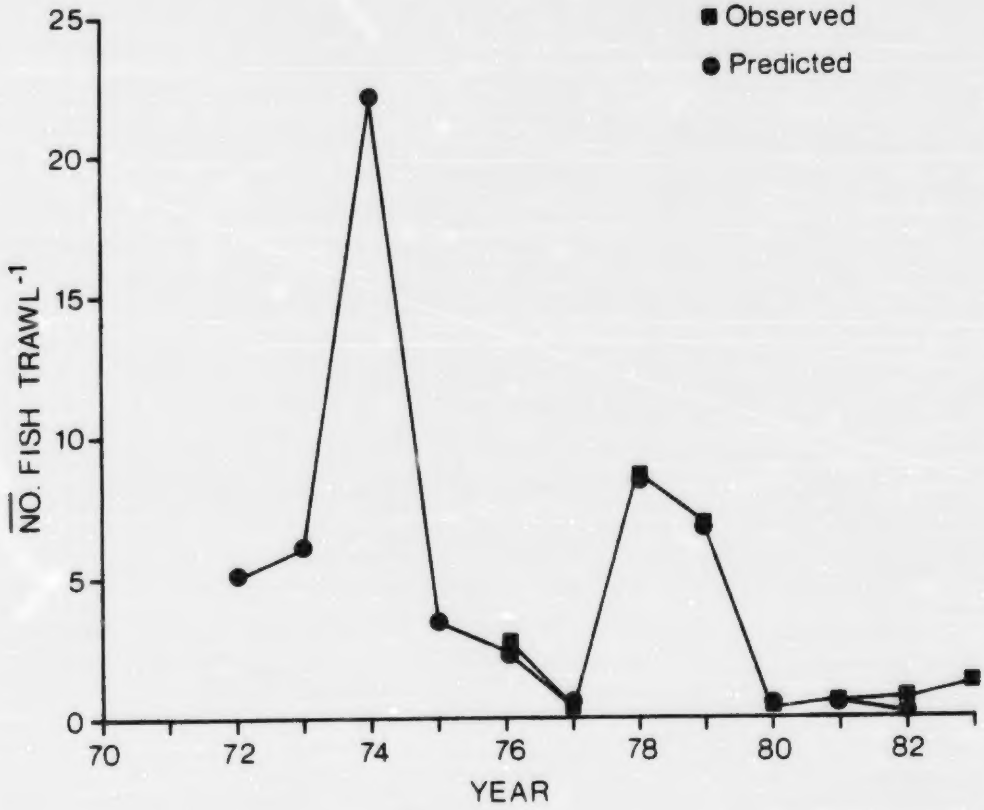


Fig. 39. Observed and predicted CUE (mean no. fish trawl^{-1}) values for pooled channel walleyes.

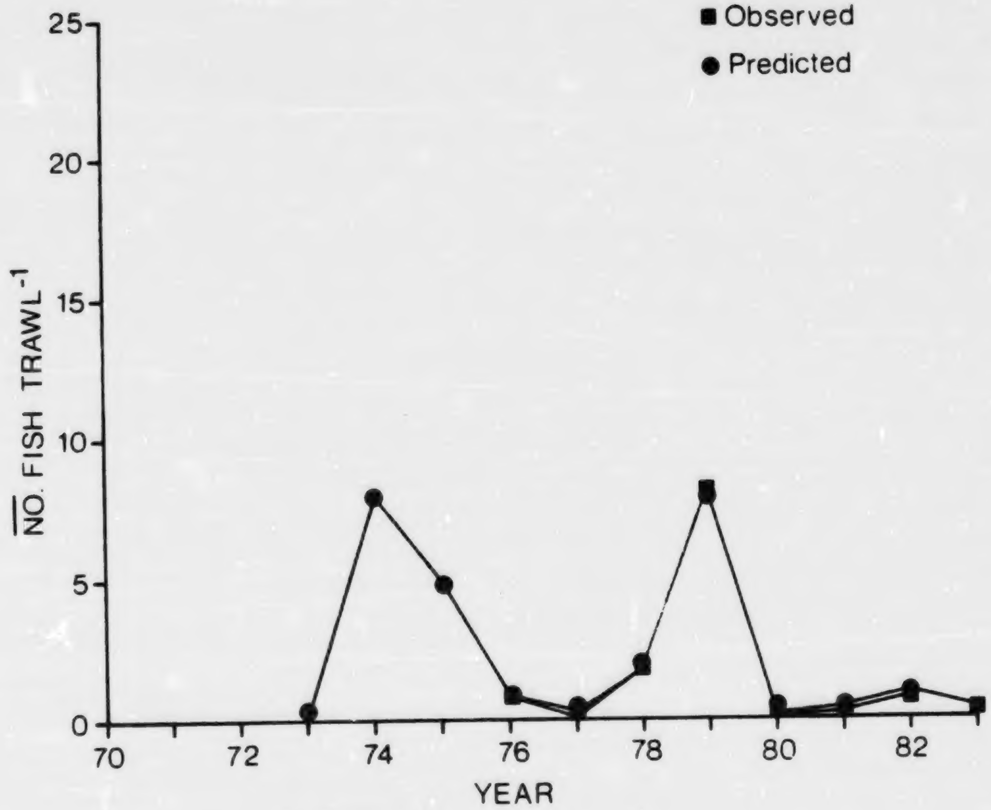


Fig. 40. Observed and predicted CUE (mean no. fish trawl^{-1}) values for south basin saugers.

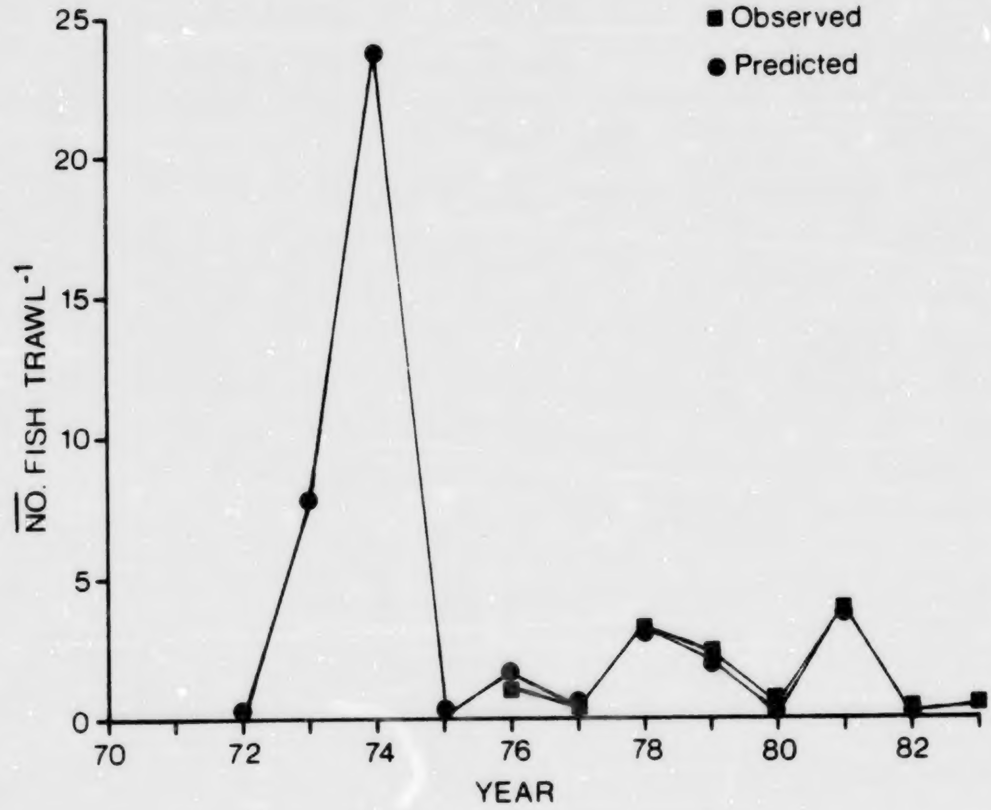


Fig. 41. Observed and predicted CUE (mean no. fish trawl^{-1}) values for southern channel saugers.

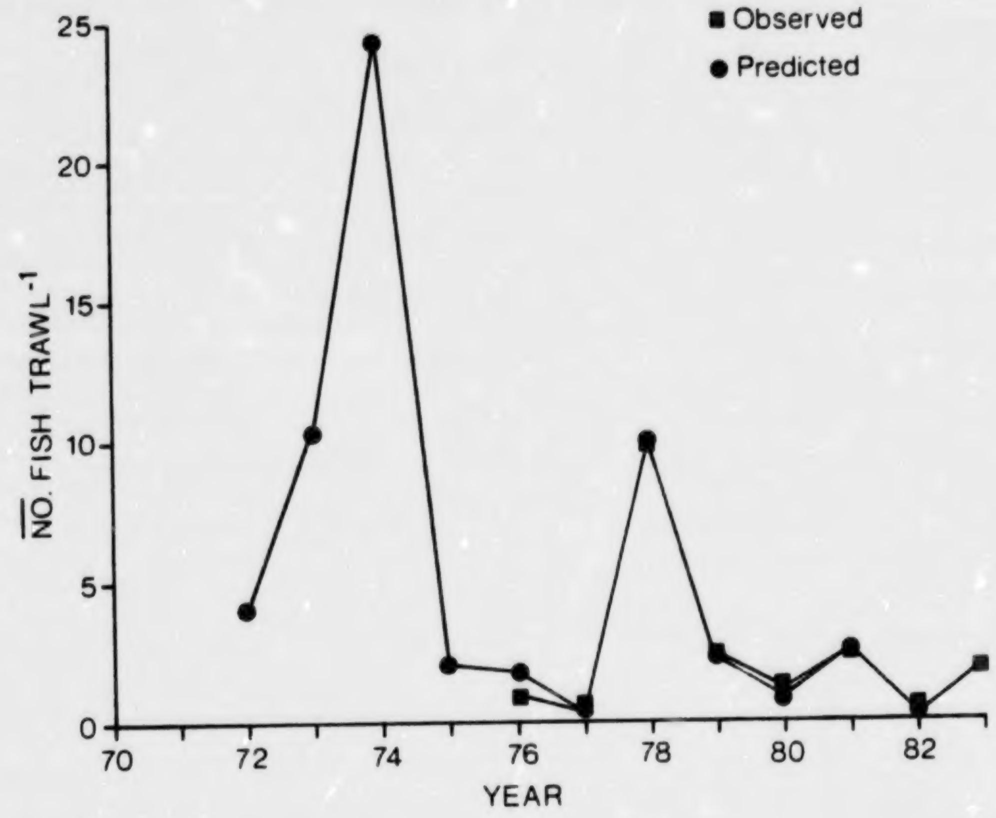


Fig. 42. Observed and predicted CUE (mean no. fish trawl^{-1}) values for pooled channel saugers.

walleyes and saugers in the south basin and channel were produced in 1974. Since the highest warming rates and flow rates occured in 1974 and 1979, it is surprising that the highest walleye CUE values in the south basin and channel were observed in 1978 while the 1978 channel sauger cohort was strong and the 1979 south basin sauger cohort was strong.

This indicates that the south channel area is not as discrete as the entire channel area as defined by Kristofferson (1985). Thus the south channel case will be eliminated from further analyses in this report and the pooled (north and south) channel case will be treated as a spatially separate case. The mean May flow rates of rivers in the south basin and in the channel were all highly correlated with each other. Manigotagan River flow rate was an important CUE indicator variable in both areas, especially for south basin saugers and channel walleyes. Warming rate was an important CUE indictor variable only for south basin saugers (Appendix A - simple correlations).

These simple MLR models predicting walleye and sauger CUE as a function of warming rates and river flow rates do not account for annual variations in the size of spawning stocks escaping from the commercial fishery.

Cohort Biomass

Annual estimates of individual mean body weight, $\overline{w}$, and age compositions determined by experimental netting were used to estimate age - specific total biomass, B, for cohorts of south and north basin walleyes (Tables 22,23), south and north basin saugers (Tables 24,25) and north basin whitefish (Table 26). The number of newborn fish in each cohort, N_o, was arbitrarily set at 1000. Age-specific frequencies of mature females, %matF, in each cohort were interpolated from the maturity curves listed on Table 15. Spawning female biomass, spawn B, was the product of B and %matF. Spawn B was not corrected for sex ratios because the majority of fish in commercial catches tended to be females and because sex ratios of the major stocks tended to change erractically from year to year (Table 27). The pre and post 1979 ageing discrepancy depicted in Figs. 11-16 produced anomalies in estimates of $\overline{w}$, N and B in many instances (Tables 22-26). A lack of annual maturity estimates and standardized commercial catch samples during 1972-1978 precluded estimates of spawn B and spawn B escaping the fishery for major fractions of earlier cohorts. Plots of total B in each cohort of south basin walleye (Fig. 43), south basin sauger (Fig. 44) and north basin whitefish (Fig. 45) depict temporal changes in total B assuming constant recruitment (i.e., N_o = 1000 fish for each cohort.) South basin walleye biomasses of the 1974-76 and 1978-79 cohorts were relatively strong (Fig. 43). The 1974, 1975 and 1979

Table 21. Observed and predicted walleye and sauger CUE values and values of independent variables.

Lake area	Cohort	Observed CUE (mean no. fish trawl $^{-1}$)		Warming rate (°C day^{-1})	May mean flow rate (m^3 sec^{-1})				Predicted CUE (mean no. fish trawl^{-1})	
		0+ walleye	0+ sauger		Red	Winnipeg	Manigotagan	Brokenhead	0+ walleye	0+ sauger
South basin	1972	-	-	0.288	623	1400	30.6	6.33	6.0561	−0.0805
	1973	-	-	0.178	71	456	17.5	2.14	7.9439	−2.2039
	1974	-	-	0.309	1780	2200	74	53.7	24.7391	7.8644
	1975	-	-	0.304	1170	1380	21	6.6	−5.5238	4.7653
	1976	3.2673	0.8713	0.256	563	720	19	4.63	3.1894	0.7997
	1977	0.1361	0.0340	0.249	57.9	148	1.46	0.171	0.3476	0.2283
	1978	8.0566	1.7799	0.227	493	977	25.6	15.5	8.0634	1.7861
	1979	2.5789	8.0632	0.319	2200	1620	48.5	23.4	2.5669	8.0522
	1980	0.4253	0.1034	0.239	99.1	735	8.23	1.41	0.4248	0.1029
	1981	0.3185	0.3778	0.198	59.3	264	3.07	0.252	0.0478	0.1291
	1982	1.0074	0.8015	0.163	495	766	16.9	3.98	1.1502	0.9327
	1983	2.7000	0.4200	-	334	573	6.75	4.53		
					Fisher	Berens	Manigotagan	Pigeon		
South channel	1972	-	-	0.288	1.73	55.3	30.6	104	8.9444	−3.3652
	1973	-	-	0.178	0.349	32.6	17.5	73.5	11.8839	7.7444
	1974	-	-	0.309	28.1	59.8	74	122	32.6566	23.8174
	1975	-	-	0.304	1.11	36.8	21	66.4	5.7345	−3.7356
	1976	2.7500	1.1250	0.256	6.01	38	19	74.1	2.7782	1.6775
	1977	0.2708	0.3542	0.249	0.552	9.61	1.46	16.4	0.2709	0.3568
	1978	16.5526	3.2763	0.227	1.87	36.1	25.6	6.13	16.5519	3.2622
	1979	6.8000	2.3500	0.319	19.1	74.4	48.5	135	6.7917	2.1871
	1980	0.2917	0.3750	0.239	0.486	27.3	8.23	57.2	0.2777	0.1012
	1981	1.1400	4.0400	0.198	1.09	18.1	3.07	40	1.1334	3.9116
	1982	1.0370	0.1605	0.163	3.68	58.5	16.9	111	1.0382	−3.7376
	1983	1.9800	0.4900	-	1.27	26.3	6.75	58.7		
North and south channel (pooled)	1972	-	-	.288	1.73	55.3	30.6	104	5.0107	4.0518
	1973	-	-	.178	.349	32.6	17.5	73.5	6.0238	10.4192
	1974	-	-	.309	28.1	59.8	74	122	22.1340	24.3915
	1975	-	-	.304	1.11	36.8	21	66.4	3.3602	2.0370
	1976	2.7500	1.1250	.256	6.01	38	19	74.1	2.5018	1.8667
	1977	0.2708	0.3542	.249	.552	9.61	1.46	16.4	0.2696	0.3577
	1978	8.5890	0.9080	.227	1.87	36.1	25.6	61.3	8.5953	9.8891
	1979	6.8000	2.3500	.319	19.1	74.4	48.5	135	6.8732	2.1313
	1980	0.1408	1.2231	.239	.486	27.3	8.23	57.2	0.2718	0.8556
	1981	0.5755	2.6226	.198	1.09	18.1	3.07	40	0.6332	2.4502
	1982	0.5563	0.0861	.163	3.68	58.5	16.9	111	−4.9486	0.1183
	1983	1.1450	1.9450	.292	1.27	26.3	6.75	58.7		

Table 22. Maturity regimes, commercial fishery effects and estimates of biomass per 1000 newborn fish for south basin walleye cohorts. Mean individual body weight=$\bar{W}$(kg.), number of fish=N, biomass, B=$\bar{W}$.N, frequency of mature females =% matF., frequency of fish in commercial catches = % comm. Dashes denote pre and post 1979 ageing discrepancy.

Cohort	Parameter	Age (years) 0	1	2	3	4	5	6	7	8	9	10
1969	$\bar{W}$	0							2.09	1.687		
	N	1000							2.4	2.2		
	Total B								5.02	3.711		
	% matF								-	-		85.45
	% comm								-	-		
	Spawn B											
1970	$\bar{W}$	0						1.523	1.549	2.400	1.327	
	N	1000						20.8	13.4	1.4	4.2	
	Total B							31.68	20.76	3.36	5.57	
	% matF							-	-	-	74.08	
	% comm							-	-	-	0.3	
	Spawn B							-	-	-	4.13	
1971	$\bar{W}$	0					1.327	0.841	1.360	1.425	0.72	
	N	1000					26.1	32.0	5.0	2.8	0.1	
	Total B						34.63	26.91	6.80	3.99	0.07	
	% matF						-	-	-	58.18	98.21	
	% comm						-	-	-	0.4	0.2	
	Spawn B						-	-	-	2.32	0.07	

Table 22, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1972	$\overline{W}$	0				0.715	0.716	1.137	0.895	1.119	1.218	
	N	1000				167.9	97.5	52.3	17	0.9	0.1	
	Total B					120.05	69.81	59.47	15.22	1.01	0.12	
	% matF					-	-	-	40.37	94.8	100	
	% comm					-	-	-	1.0	2.2		
	Spawn B					-	-	-	6.14	0.96	0.12	
1973	$\overline{W}$	0			0.474	0.404	0.613	0.748	1.033	1.022	1.120	3.000
	N	1000			180.9	66.2	30.8	83.6	0.03	1.10	0.01	6.2
	Total B				85.75	26.74	18.88	62.53	0.03	0.10	0.01	18.6
	% matF				-	-	-	24.79	85.86	99.42	100	100
	% comm				-	-	-	2.2	1.4	1.0	1.0	0
	Spawn B				-	-	-	15.50	0.03	0.1	0.01	
1974	$\overline{W}$	0		0.376	0.490	0.582	0.551	0.756	0.846	1.460	0	0
	N	1000		571.2	462.8	137.4	266.3	2.2	1.2	0.2	0	0
	Total B			214.77	226.77	79.97	146.73	1.66	1.02	0.29	0	0
	% matF			-	-	-	13.82	66.91	96.3	99.02	100	100
	% comm			-	-	-	10.1	0.6	0.4	0.9	0.3	0
	Spawn B			-	-	-	20.28	1.11	0.98	0.29	0	0

Table 22, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1975	$\bar{w}$	0	0.150	0.328	0.457	0.474	0.654	0.757	1.340	1.910	0	0
	N	1000	26.7	252.2	231.9	366.9	1.3	0.5	0.5	12.3	0	0
	Total B		4.01	82.72	105.98	173.91	0.85	0.38	0.67	23.49	0	0
	% matF		-	-	-	7.24	40.23	79.92	93.599	48.7	0	0
	% comm		-	-	-	43.64	9.2	1.2	1.0	9.3	0	0
	Spawn B		-	-	-	125.91	0.34	0.30	0.63	23.18	0	0
1976	$\bar{w}$	0	0.034	0.112	0.347	0.422	0.549	0.735	1.063	1.564		
	N	1000	4.1	46.9	533.3	202.6	4.2	2.6	1.0	61.7		
	Total B		1.39	5.25	185.06	85.50	2.31	1.91	1.06	96.5		
	% matF		-	-	-	3.66	18.3	37.24	67.68	93.26		
	% comm					41.39	27.4	9.2	4.2	22.7		
	Spawn B					3.13	0.42	0.71	0.72	90.00		
1977	$\bar{w}$	0	0.018	0.105	0.149	0.360	0.562	0.740	1.057			
	N	1000	3.7	7.9	49.6	0.6	1.1	1.7	135.8			
	Total B		0.07	0.83	7.39	0.22	0.62	1.26	143.54			
	% matF		-	-	1.82	6.94	8.22	23.09	71.52			
	% comm		-	-	0.8	18.4	15.6	4.8	6.4			
	Spawn B		-	-	0.13	0.02	0.05	0.29	102.66			

Table 22, cont'd.

Cohort	Parameter	Age (years) 0	1	2	3	4	5	6	7	8	9	10
1978	$\overline{W}$		-	0.104	0.125	0.403	0.523	0.867				
	N		0	7.1	0.1	4.2	5.0	203.7				
	Total B			0.74	0.01	1.69	2.62	176.61				
	% matF			0.89	2.42	1.33	4.13	31.32				
	% comm			0	35.2	47.6	28.2	17.47				
	Spawn B			0.01	0	0.02	0.11	55.31				
1979	$\overline{W}$				0.262	0.446	0.560					
	N			0	0.2	1.5	395.1					
	Total B				0.05	0.67	221.26					
	% matF				0.2	0.61	7.65					
	% comm				25.8	55.8	297.3					
	Spawn B				0	0	16.93					
1980	$\overline{W}$		-	-	0.284	0.388						
	N			0	0.1	172.8						
	Total B				0.03	67.05						
	% matF				.09	1.48						
	% comm			0.1	4.90	24.53						
	Spawn B				0	0.99						

Table 22, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1981	$\bar{W}$				0.115							
	N				12.3							
	Total B				1.41							
	% matF				0.27							
	% comm											
	Spawn B				0							

Table 23. Maturity regimes, commercial fishery effects and estimates of biomass per 1000 newborn fish for north basin walleye cohorts. Mean individual body weight=$\overline{w}$(kg), number of fish=N, biomass, B=$\overline{w}$.N, frequency of mature females =% matF, frequency of fish in commercial catches =% comm.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1970	$\overline{w}$	0									1.090	0.705
	N	1000									8.3	6.9
	Total B										9.05	4.86
	% matF										90.02	97.34
	% comm										0.50	0.96
	Spawn B										8.15	4.73
	Escaped B										8.11	4.69
1971	$\overline{w}$	0								1.014	1.160	
	N	1000								41.7	10.4	
	Total B									42.28	12.06	
	% matF									75.58	89.47	91.68
	% comm									5.73	2.35	0.41
	Spawn B									31.96	10.79	-
	Escaped B									30.12	10.54	-
1972	$\overline{w}$	0							0.816	1.017	0.985	1.390
	N	1000							127.8	117.6	14.1	3.6
	Total B								104.28	119.60	13.89	5.00
	% matF								51.5	66.37	81.67	?
	% comm								44.10	13.57	0.91	0.40
	Spawn B								53.70	79.38	11.34	?
	Escaped B								30.02	68.61	11.24	?

Table 23, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1973	$\overline{W}$	0						0.604	0.764	0.858	1.060	
	N	1000						213.9	204.2	75.1	43.2	
	Total B							129.20	156.01	64.44	45.79	
	% matF							26.70	31.43	54.34	?	97.44
	% comm							31.31	28.63	12.66	3.87	0.13
	Spawn B							34.50	49.03	41.46	?	-
	Escaped B							23.70	35.00	36.21	?	
1974	$\overline{W}$	0					0.461	0.652	0.811	1.060	1.890	
	N	1000					344.4	287.5	126.8	143.9	4.7	
	Total B						158.77	252.65	102.83	152.53	8.88	
	% matF						11.11	9.62	42.21	?	88.99	
	% comm						15.12	40.71	47.72	22.80	5.87	
	Spawn B						17.64	24.30	43.40	?	7.90	
	Escaped B						14.97	14.41	22.69	?	7.44	
1975	$\overline{W}$	0				0.388	0.534	0.723	0.859	1.505		
	N	1000				250.0	197.2	286.4	514.4	9.3		
	Total B					970.00	105.30	207.07	441.87	14.0		
	% matF					4.11	2.41	22.83	?	63.16		
	% comm					2.49	11.75	22.59	36.67	21.73		
	Spawn B					39.87	2.54	1.61	?	8.84		
	Escaped B					38.87	2.24	1.25	?	6.92		

Table 23, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1976	$\overline{W}$	0			0.294	0.426	0.565	0.643	1.216			
	N	1000			13.9	58.8	333.3	205.00	72.4			
	Total B				4.09	25.05	188.31	131.82	88.04			
	% matF				1.45	0.57	10.7	?	26.66			
	% comm				0.25	1.92	10.44	29.07	33.87			
	Spawn B				0.06	0.14	20.15	?	23.47			
	Escaped B				0.06	0.14	18.05	?	15.62			
1977	$\overline{W}$	0			0.095	0.408	0.466	0.912				
	N	1000			13.8	16.4	39.6	149.5				
	Total B				1.31	6.69	18.45	136.34				
	% matF			0.50	0.13	4.63	?	7.16				
	% comm			0.08	0.11	4.76	5.20	17.47				
	Spawn B				0	0.31	?	9.76				
	Escaped B				0	0.30	?	8.06				
1978	$\overline{W}$	0			0.280	0.464	0.681					
	N	1000			16.4	43.2	317.8					
	Total B				4.59	20.04	216.42					
	% matF		0.17	0	1.93	?	1.61					
	% comm				0.20	0	13.60					
	Spawn B				0.09	?	3.48					
	Escaped B				0.09	?	3.01					

Table 23, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1979	$\bar{W}$	0	0.030	0.103	0.215	0.507						
	N	1000	3.5	9.4	7.2	343.5						
	Total B		0.11	0.97	1.55	174.15						
	% matF		0	0.79	?	0.35						
	% comm		0	0	0	6.93						
	Spawn B		0	.01	?	0.61						
	Escaped B		0	.01	?	0.54						
1980	$\bar{W}$	0	0.030		0.373							
	N	1000	2.3		95.8							
	Total B		0.07		35.7							
	% matF		0.32	?	0.07							
	% comm		0	0	0.27							
	Spawn B		0	?	.02							
	Escaped B		0	?	.02							
1981	$\bar{W}$	0		0.263								
	N	1000		7.0								
	Total B			1.84								
	% matF		?	0.02								
	% comm			0								
	Spawn B			0								
	Escaped B			0								

Table 24. Maturity regimes, commercial fishery effects and estimates of biomass per 1000 newborn fish for south basin sauger cohorts. Mean individual body weight=$\bar{w}$(kg.), number of fish=N, biomass, B=$\bar{w}$.N, frequency of mature females=%matF, frequency of fish in commercial catches =%comm. Dashes denote pre and post 1979 ageing discrepancy.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1969	$\bar{w}$	0							1.080			
	N	1000							1.5			
	Total B								1.62			
	% matF								-			
	% comm								-			
	Spawn B								-			
1970	$\bar{w}$	0						0.680	0.740			0.470
	N	1000						1.5	0.4			4.4
	Total B							1.02	0.296			2.07
	% matF							-	-			100
	% comm							-	-			0
	Spawn B							-	-			2.07
1971	$\bar{w}$	0						0.576	0.603	0.350	0.329	0.590
	N	1000					11.9	4.2	3.4	1.5	15.3	0.6
	Total B						6.854	2.533	1.034	0.53	5.03	0.35
	% matF						-	-	-	100	100	100
	% comm						-	-	-	0	0.10	0
	Spawn B						-	-	-	0.53	5.03	0.35

Table 24, cont'd.

Cohort	Parameter	Age (years) 0	1	2	3	4	5	6	7	8	9	10
1972	$\bar{W}$	0				0.419	0.443	1.060	0.265	0.370	0.500	
	N	1000				97.8	15.2	1.4	3.0	59.0	3.7	
	Total B					40.98	6.73	1.48	0.79	21.83	1.85	
	% matF					-	-	-	100	100	100	
	% comm					-	-	-	1.0	0.20	0	
	Spawn B					-	-	-	0.79	21.83	1.85	
1973	$\bar{W}$	0			0.312	0.336	0.530	0.300	0.335	0.440	0.710	
	N	1000			395.8	111.2	14.5	56.8	148.5	33.2	1.2	
	Total B				123.49	37.36	7.69	17.04	49.75	14.61	0.85	
	% matF				-	-	-	99.10	99.19	99.58	100	
	% comm				-	-	-	3.80	0.90	0	0	
	Spawn B				-	-	-	16.89	49.35	14.55	0.85	
1974	$\bar{W}$	0		0.189	0.267	0.374	0.286	0.302	0.401	0.588	1.22	
	N	1000		315.9	381.9	166.8	400.6	331.9	189.8	4.7	3.1	
	Total B			59.71	101.97	62.38	114.57	100.23	76.11	2.76	3.78	
	% matF			-	-	-	96.54	96.59	97.71	99.38	100	
	% comm			-	-	-	32.80	12.30	0.2	0	0	
	Spawn B			-	-	-	110.61	96.81	74.37	2.74	3.78	

Table 24, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1975	$\bar{W}$	0	0.091	0.174	0.275	0.264	0.267	0.358	0.506	0.903		
	N	1000	160.6	333.9	562.4	411.1	312.2	323.7	70.0	9.4		
	Total B		14.61	58.10	154.66	108.53	83.36	115.88	35.42	8.49		
	% matF		-	-	-	87.65	86.80	88.38	96.56	100		
	% comm		-	-	-	51.60	55.60	2.6	0.2	0		
	Spawn B		-	-	-	95.13	72.36	102.41	34.20	8.49		
1976	$\bar{W}$	0	0.097	0.182	0.244	0.225	0.302	0.426	0.608			
	N	1000	141.5	247.4	103.1	107.0	194.1	126.0	62.5			
	Total B		13.73	45.03	25.16	24.08	58.62	53.68	38.00			
	% matF		-	-	64.34	60.37	57.57	83.12	99.92			
	% comm		-	-	39.45	30.20	20.2	1.20	0			
	Spawn B		-	-	16.19	7.27	33.75	44.62	37.97			
1977	$\bar{W}$	0	.093	0.977	0.179	0.255	0.346	0.480				
	N	1000	4.1	23.9	10.9	62.0	105.0	153.1				
	Total B		0.38	23.35	19.51	15.81	36.33	73.49				
	% matF		-	31.43	26.10	19.48	46.36	99.20				
	% comm		-	1.51	0.70	60.4	2.20	0.53				
	Spawn B		-	7.34	5.09	3.08	16.84	72.90				

Table 24, cont'd.

Cohort	Parameter	Age (years) 0	1	2	3	4	5	6	7	8	9	10
1978	$\overline{W}$	0	0	0.080	0.131	0.243	0.358					
	N	1000	0	4.4	117.3	203.0	200.0					
	Total B		0	0.35	15.37	49.33	71.60					
	% matF		0	7.56	4.14	13.17	92.92					
	% comm		0	0	16.6	24.60	21.36					
	Spawn B		0	0.03	0.64	6.50	66.53					
1979	$\overline{W}$	0	0.042	0.078	0.131	0.265						
	N	1000	4.4	71.9	380.4	178.1						
	Total B		0.18	12.80	49.83	47.20						
	% matF		1.86	0.76	2.59	58.05						
	% comm		0	0	62.00	53.67						
	Spawn B		0	0.10	1.29	27.40						
1980	$\overline{W}$	0	0.030	0.102	0.172							
	N	1000	3.7	103.9	293.8							
	Total B		0.11	10.60	50.53							
	% matF		0.14	0.47	12.74							
	% comm		0	9.20	20.16							
	Spawn B		0	0.05	6.44							

Table 24, cont'd.

Cohort	Parameter	Age (years)										
		0	1	2	3	4	5	6	7	8	9	10
1981	$\overline{W}$	0	0.023	0.110								
	N	1000	5.8	84.4								
	Total B		0.13	9.28								
	% matF		0.08	1.52								
	% comm	0.6	0	4.27								
	Spawn B		0	0.14								
1982	$\overline{W}$	0	0.040									
	N	1000	15.6									
	Total B		0.62									
	% matF		0.16									
	% comm		0									
	Spawn B		0									

Table 25. Maturity regimes, commercial fishery effects and estimates of biomass (kg) per 1000 newborn fish for north basin sauger cohorts. Mean individual body weight = $\overline{w}$(kg), number of fish=N, biomass, B=$\overline{w}\cdot$N, frequency of mature females = %matF, frequency of fish in commercial catches = % comm.

Cohort	Parameter	Age (years)													
		0	1	2	3	4	5	6	7	8	9	10	11	12	13
1966	$\overline{w}$	0													0.559
	N	1000													17.7
	Total B														9.89
	%matF														-
	% comm														0
	Spawn B														9.89
	Escaped B														9.89
1967	$\overline{w}$	0												0.845	
	N	1000												25.6	
	Total B													21.63	
	%matF													-	-
	% comm													0	0
	Spawn B													21.63	3.11
	Escaped B													21.63	3.11
1968	$\overline{w}$	0											0.706	0.842	1.040
	N	1000											45.2	10.0	1.2
	Total B												31.91	8.42	1.25
	%matF												-	-	-
	% comm												0	0	0
	Spawn B												31.91	8.42	1.25
	Escaped B												31.91	8.42	1.25
1969	$\overline{w}$	0										0.640	0.807	0.850	1.170
	N	1000										66.9	22.0	1.2	3.4
	Total B											42.82	17.75	1.02	3.98
	%matF											100	100	100	100
	% comm											0	0	0	0.94
	Spawn B											42.82	17.75	1.02	3.98
	Escaped B											42.82	17.75	1.02	3.94

Table 25, cont'd.

Cohort	Parameter	Age (years) 0	1	2	3	4	5	6	7	8	9	10	11	12	13
1970	$\bar{W}$	0									0.542	0.697	0.660	1.020	
	N	1000									176.0	69.2	2.4	3.4	
	Total B										95.39	48.23	1.58	3.47	
	%matF										99.47	99.42	100	100	
	% comm										0	0	0	2.94	
	Spawn B										94.88	47.95	1.58	3.47	
	Escaped B										94.88	47.95	1.58	3.47	
1971	$\bar{W}$	0								0.486	0.580	0.749	0.965		
	N	1000								251.7	122.0	8.4	29.1		
	Total B									122.33	70.76	6.29	28.08		
	%matF									98.55	98.26	98.85	100		
	% comm									1.74	0.1	8.00	8.69		
	Spawn B									120.56	69.53	6.22	28.08		
	Escaped B									118.46	69.46	5.72	25.64		
1972	$\bar{W}$	0							0.430	0.506	0.697	0.815			
	N	1000							219.3	229.0	44.8	63.2			
	Total B								94.30	115.87	31.23	51.51			
	%matF								96.06	94.95	97.53	99.80			
	% comm								9.65	2.39	0	17.51			
	Spawn B								90.58	110.02	30.46	51.41			
	Escaped B								81.84	107.39	30.46	42.41			
1973	$\bar{W}$	0						0.369	0.425	0.571	0.692	1.570			
	N	1000						150.4	229.7	120.2	136.8	0.8			
	Total B							55.50	97.62	68.63	94.67	1.26			
	%matF							89.77	86.21	94.78	99.17	100			
	% comm							38.42	9.93	1.2	29.01	0			
	Spawn B							49.82	84.16	65.05	93.88	1.26			
	Escaped B							30.68	75.80	64.27	66.65	1.26			

Table 25, cont'd.

Cohort	Parameter	Age (years) 0	1	2	3	4	5	6	7	8	9	10	11	12	13
1974	$\bar{w}$	0					0.306	0.361	0.536	0.589	1.150				
	N	1000					39.3	201.1	168.30	372.6	5.8				
	Total B						12.03	72.60	90.21	219.46	6.67				
	%matF						75.95	67.52	89.31	96.67	100				
	% comm						43.05	26.84	2.81	28.61	0.4				
	Spawn B						9.14	49.02	80.57	212.15	6.67				
	Escaped B						5.20	35.86	78.30	151.46	6.67				
1975	$\bar{w}$	0				0.274	0.262	0.443	0.468	0.980					
	N	1000				7.9	92.3	310.1	276.9	53.6					
	Total B					2.16	24.18	137.33	129.59	52.53					
	%matF					53.20	40.88	79.36	87.49	100					
	% comm					7.14	32.76	16.06	8.69	2.80					
	Spawn B					1.15	9.88	108.99	113.38	52.53					
	Escaped B					1.07	6.65	91.48	103.53	51.06					
1976	$\bar{w}$	0				0.199	0.385	0.410	0.736						
	N	1000				20.9	221.2	80.3	188.9						
	Total B					4.16	85.16	32.92	139.3						
	%matF				29.03	18.69	63.9	62.78	100						
	% comm					32.76	46.59	2.94	13.87						
	Spawn B					0.78	54.42	20.67	139.03						
	Escaped B					0.52	29.06	20.06	119.75						
1977	$\bar{w}$	0			0.985	0.321	0.301	0.575							
	N	1000			4.4	86.5	25.6	396.0							
	Total B				0.37	27.77	7.71	227.70							
	%matF			12.83	7.10	44.89	28.93	99.11							
	% comm				4.11	32.13	0.27	42.40							
	Spawn B				.03	12.47	2.23	225.67							
	Escaped B				.03	8.46	2.22	129.99							

Table 25, cont'd.

Cohort	Parameter	Age (years)													
		0	1	2	3	4	5	6	7	8	9	10	11	12	13
1978	$\bar{w}$	0		0.070	0.222	0.115	0.430								
	N	1000		2.2	30	3.4	276.4								
	Total B			0.15	6.66	0.39	118.85								
	%matF		5.03	2.48	27.27	8.94	92.57								
	% comm			1.2	0	0.13	30.53								
	Spawn B			0	1.82	.03	110.02								
	Escaped B			0	1.82	.03	76.43								
1979	w	0	0.050	0.158	0.140	0.339									
	N	1000	2.2	4.8	3.4	66.0									
	Total B		0.11	0.76	0.48	22.37									
	%matF		0.84	14.72	2.31	58.3									
	% comm		0	0	0	9.73									
	Spawn B		0	0.11	0.01	13.04									
	Escaped B		0	0.11	0.01	11.77									
1980	$\bar{w}$	0	0.030	0.080	0.215										
	N	1000	1.2	1.7	9.9										
	Total B		0.04	0.14	2.13										
	%matF		7.36	0.57	13.55										
	% comm		0	0	0.27										
	Spawn B		0	0	0.29										
	Escaped B		0	0	0.29										
1981	$\bar{w}$			0.107											
	N	1000		2.5											
	Total B			0.268											
	%matF		0.14	1.73											
	% comm			0											
	Spawn B			0											
	Escaped B			0											

Table 26. Maturity regimes, commercial fishery effects and estimates of biomass (kg) per 1000 newborn fish for north basin whitefish cohorts. Mean individual body weight = $\overline{w}$ (kg), number of fish = N, biomass, B = $\overline{w}\cdot N$, frequency of mature females = %mat F, frequency of fish in commercial catches = %comm. Dashes denote pre and post 1979 ageing discrepancy.

Cohort	Parameter	Age (years)											
		0	1	2	3	4	5	6	7	8	9	10	11
1966	$\overline{w}$	0						1.313	1.728	1.97	1.658	1.693	1.932
	N	1000						65.1	12.9	1.4	6.3	9.8	2.3
	Total B							85.48	22.29	2.76	10.45	16.59	4.44
	%mat F												
	%comm												
	Spawn B												
	Escaped B												
1967	$\overline{w}$	0					1.038	1.394	1.730	1.608	1.539	1.409	
	N	1000					614	150.5	17.7	18.4	23.3	7.0	
	Total B						637.33	209.80	30.62	29.59	35.86	9.86	
	% mat F												
	% comm												
	Spawn B												
	Escaped B												
1968	$\overline{w}$	0				0.777	1.127	1.392	1.457	1.423	1.399	2.380	2.147
	N	1000				306.5	414.3	188.7	57.6	62.0	22.2	0.5	2.1
	Total B					238.15	466.92	262.67	83.92	88.23	31.06	1.19	4.51
	% mat F												
	% comm												0.32
	Spawn B												
	Escaped B												
1969	$\overline{w}$	0			0.400	0.776	1.109	1.307	1.236	1.266	1.589	2.080	1.940
	N	1000			13.0	322.4	400.0	161.3	124.9	60.2	5.6	0.7	1.0
	Total B				5.20	250.18	443.60	210.82	154.38	76.21	8.90	1.46	1.94
	% mat F											100	100
	% comm											0.56	0
	Spawn B											1.46	1.94
	Escaped B											1.45	1.94

1970	$\bar{w}$	0	0.227	0.479	0.762	1.110	1.034	1.088	1.440	1.485	1.555	
	N	1000	0.5	88.5	244.5	223.2	162.7	74.6	13.3	7.1	6.2	
	Total B		0.11	42.39	186.31	247.75	168.23	81.16	19.15	10.54	9.64	
	% mat F									99.66	98.80	
	% comm									0.52	0	
	Spawn B									10.50	9.52	
	Escaped B									10.45	9.52	
1971	$\bar{w}$	0	0.253	0.382	0.707	0.743	0.911	1.189	1.216	1.336	1.500	2.010
	N	1000	13.6	105.3	165.9	163.4	128.4	33.9	32.4	15.8	0.3	0.7
	Total B		3.44	40.22	117.29	121.41	116.97	40.31	39.40	21.11	0.45	1.41
	% mat F								98.99	96.54	99.1	100
	% comm								2.66	0.81	0.20	0
	Spawn B								39.00	20.38	0.45	1.41
	Escaped B								37.96	20.21	0.45	1.41
1972	$\bar{w}$	0	0.237	0.421	0.549	0.700	0.942	1.010	1.125		1.100	
	N	1000	42.4	348.6	344.1	384.6	150.4	97.3	39.2		2.7	
	Total B		10.05	146.76	188.91	269.22	141.68	98.27	44.1		2.97	
	% mat F							96.98	90.46	97.70	100	
	% comm							12.62	3.17	0.40	0.10	
	Spawn B							95.30	39.89		2.97	
	Escaped B							83.28	38.63		2.97	
1973	$\bar{w}$	0	0.239	0.324	0.521	0.733	0.898	1.034	1.377	1.325	1.270	
	N	1000	17.8	104.7	234.5	462.5	282.1	126.3	4.6	4.1	0.3	
	Total B		4.25	33.92	122.17	339.01	253.33	130.59	6.15	5.43	0.38	
	% mat F						91.29	76.28	94.26	100	100	
	% comm						38.45	12.56	0.80	0.30	0	
	Spawn B						231.26	99.61	5.80	5.43	0.38	
	Escaped B						142.34	87.10	5.75	5.41	0.38	
1974	$\bar{w}$	0	0.284	0.303	0.544	0.781	0.927	1.162	1.091	1.412		
	N	1000	37.0	80.6	294.1	384.3	331.4	30.6	14.4	4.1		
	Total B		10.51	24.42	159.99	300.14	307.21	35.58	15.71	5.79		
	% mat F					77.38	52.17	86.39	99.93	99.87		
	5 comm					39.34	34.44	3.30	4.70	0.40		
	Spawn B					232.24	160.27	30.74	15.70	5.78		
	Escaped B					140.88	105.07	29.72	14.96	5.76		
1975	$\bar{w}$	0	0.242	0.371	0.601	0.785	1.001	1.022	1.245			
	N	1000	4.6	35.9	175.6	292.7	174.3	109.3	28.6			
	Total B		1.11	13.32	105.54	229.77	174.47	111.70	35.61			

	% mat F					52.75	27.01	71.05	99.38	99.12
	% comm					4.96	40.58	24.60	36.40	2.67
	Spawn B					55.67	62.06	123.96	111.01	35.30
	Escaped B					52.91	36.88	93.47	70.60	34.35
1976	$\overline{w}$	0		0.227	0.361	0.508	0.914	0.935	1.107	
	N	1000		3.9	16.9	116.5	350.5	240.5	142.1	
	Total B			0.89	6.1	59.18	320.36	224.87	157.30	
	% mat F				26.70	11.16	48.70	94.62	94.13	
	% comm				0.16	8.24	56.90	46.50	28.27	
	Spawn B				1.63	6.60	156.02	212.77	148.07	
	Escaped B				1.63	6.06	67.24	113.83	106.21	
1977	$\overline{w}$	0		0.260	0.366	0.762	0.729	0.901		
	N	1000		7.0	67.0	273.3	224.1	211.3		
	Total B			1.82	24.52	208.25	163.37	190.38		
	% mat F			10.62	4.09	26.85	65.77	69.55		
	% comm			0.04	0.07	13.80	10.90	45.20		
	Spawn B			0.19	1.00	55.92	107.45	132.41		
	Escaped B			0.19	1.00	48.20	95.94	72.56		
1978	$\overline{w}$	0		0.213	0.458	0.487	0.633			
	N	1000		2.9	158.5	350.5	402.2			
	Total B			0.62	72.59	157.05	254.59			
	% mat F		3.73	1.42	12.43	17.35	24.56			
	% comm					1.10	21.60			
	Spawn B			0.01	9.02	27.25	62.53			
	Escaped B			0.01	9.02	26.95	13.51			
1979	$\overline{w}$	0		0.315	0.347	0.470				
	N	1000		7.9	53.6	203.5				
	Total B			2.49	18.60	95.65				
	% mat F		0.49	5.21	2.24	4.44				
	% comm					1.87				
	Spawn B			0.13	0.42	4.25				
	Escaped B			0.13	0.42	4.17				
1980	$\overline{w}$	0			0.357					
	N	1000			7.5					
	Total B				2.68					
	% mat F		2.08	0.25	0.66					
	% comm									
	Spawn B				0.02					
	Escaped B				0.02					

1981	$\bar{w}$	0		0.180
	N	1000		0.3
	Total B			0.05
	% mat F		0.03	0.09
	% comm			
	Spawn B			
	Escaped B			

Table 27. Annual estimates of sex ratios (male:female) of walleye, sauger and whitefish stocks.

Year	Lake area				
	South basin		North basin		
	Walleye	Sauger	Walleye	Sauger	Whitefish
1979	1.69	1.81	0.37	0.41	0.78
1980	0.36	1.36	0.44	0.61	0.93
1981	1.00	2.01	0.46	1.18	0.92
1982	0.38	0.73	0.36	0.46	0.89
1983	0.32	0.5	0.37	0.36	0.98

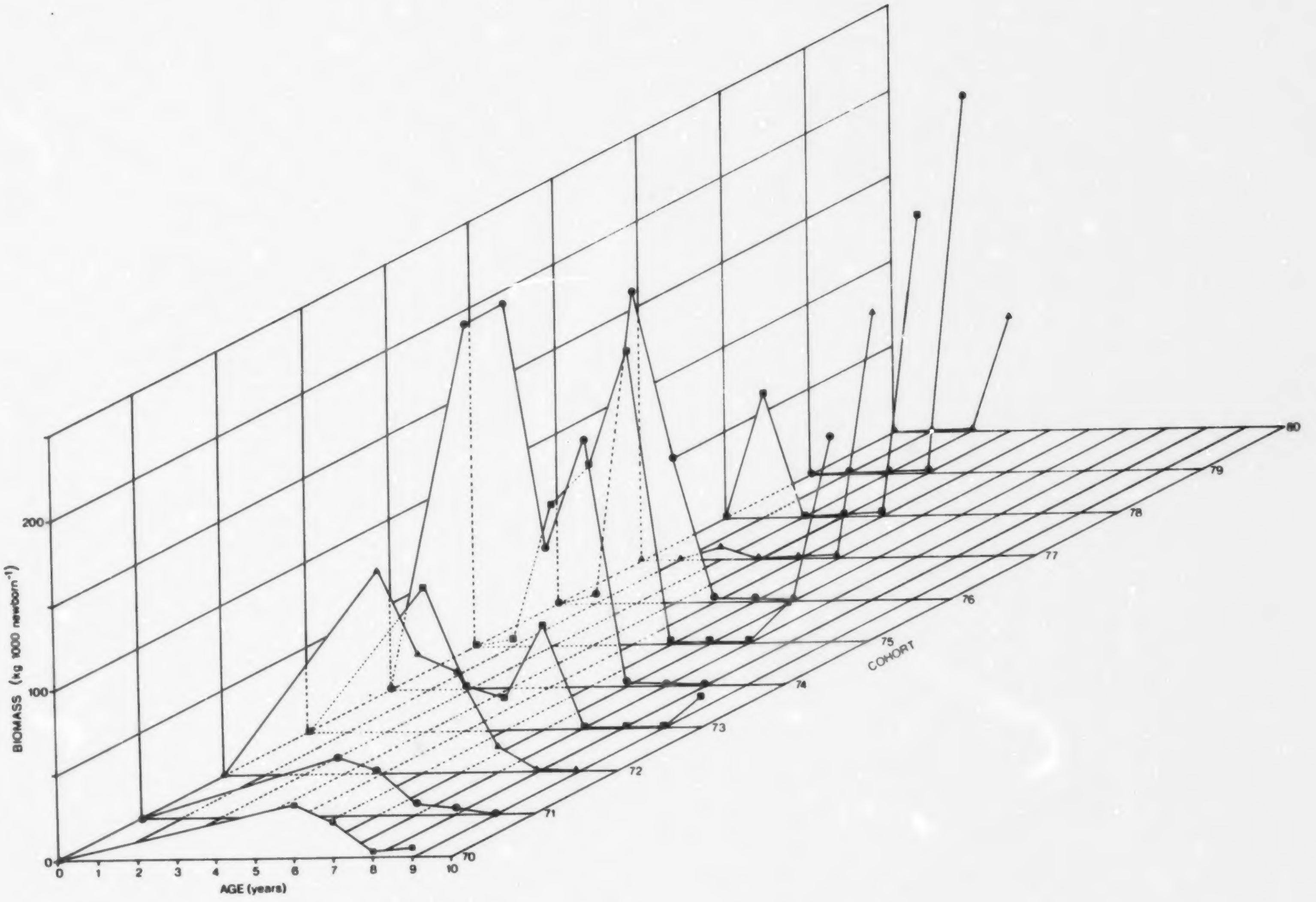


Fig. 43. Cohort biomass curves of south basin walleyes.

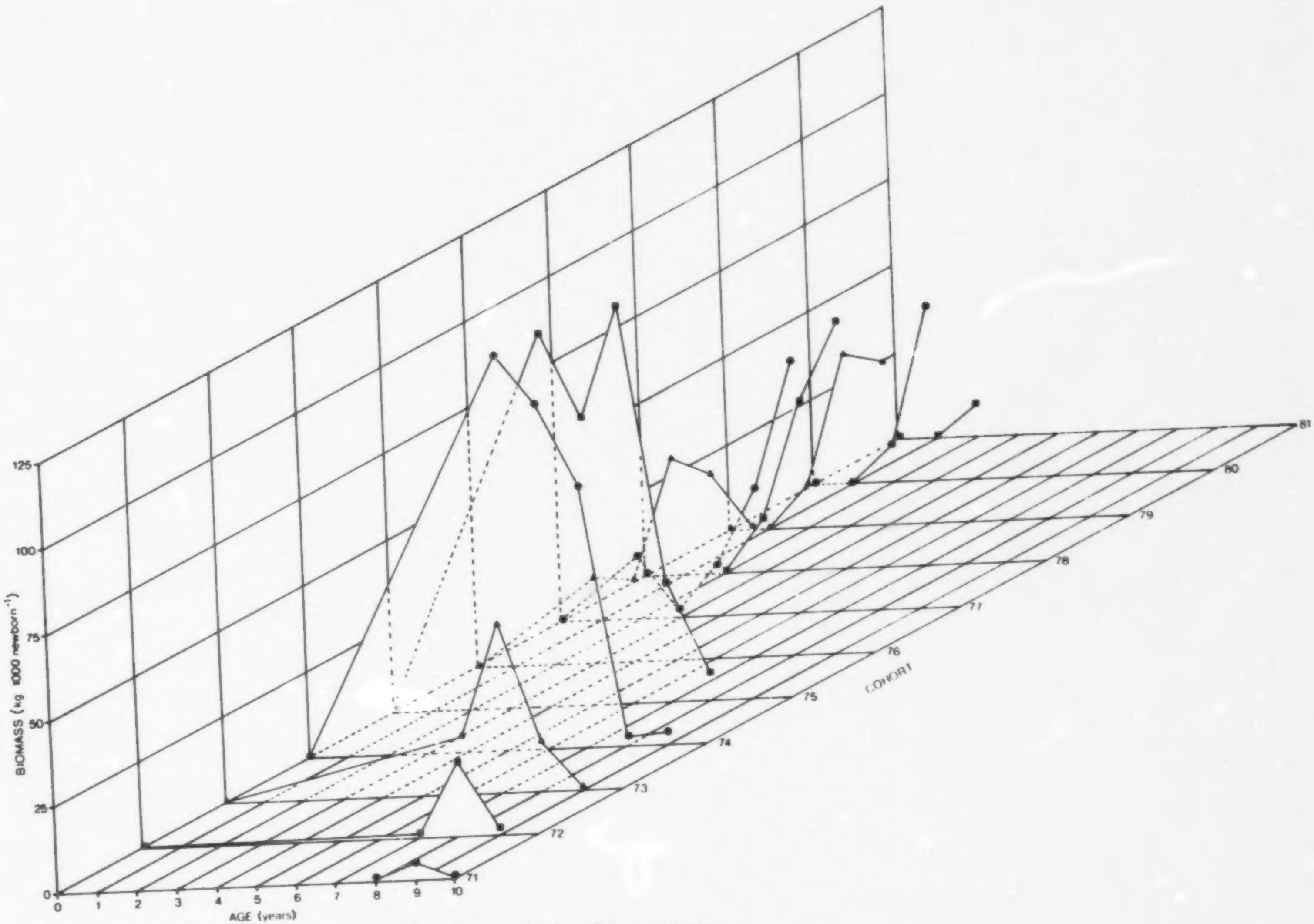


Fig. 44. Cohort biomass curves of south basin saugers.

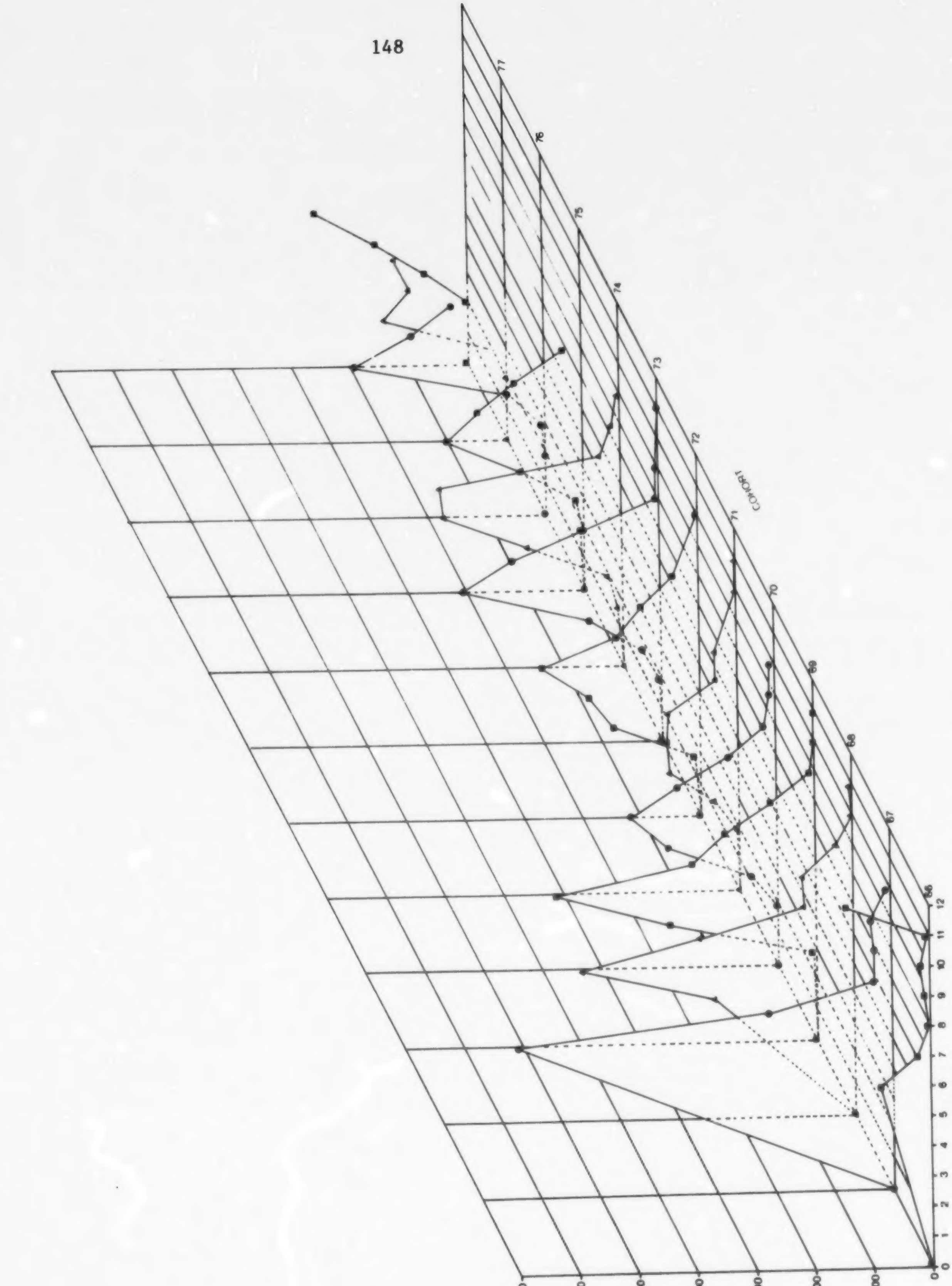


Fig. 45. Cohort biomass curves of north basin whitefish.

(incomplete) cohorts of south basin saugers contributed relatively large biomasses (Fig. 44).

Cohort biomasses of south basin walleyes and saugers were reconstructed assuming that predicted trawl CUE values (Table 23) were accurate indicators of variable recruitment i.e., for each cohort, $N_o = 1000 + (1000 \cdot \text{predicted trawl CUE})$. A constant value of 1000 was included in each N_o to account for negative predicted trawl CUE values. Thus, the first model depicts cohort biomass assuming constant recruitment and the second model depicts cohort biomass as a function of variable recruitment.

In each case, the amount of spawning female biomass escaping the fishery during each year from 1979 to 1983 was estimated by: Spawn B - (% comm $\cdot$ Spawn B) (Table 28). In southern Lake Winnipeg, escaped female walleye spawning biomass declined drastically from 1979-1982 and increased in 1983. Spawning walleye biomass in the north basin was higher during each year from 1979-1982 but declined over the long term. From 1979 to 1981, escaped female sauger spawning biomass increased in the south basin and decreased in the north basin. In 1982 and 1983, northern sauger spawning biomass was higher but suffered substantially higher removal rates. Southern sauger spawning biomass was extremely low in 1982 and improved dramatically in 1983. Whitefish spawning biomass remained relatively constant during the five year period but a high removal rate in 1983 decreased the escapement (Table 28).

Table 28. Annual estimates of spawning female biomass removed by the fishery and escaping the fishery in Lake Winnipeg. Figures in parentheses are removal rates (%).

Lake area	Year	Spawning female biomass (kg)								
		Total			Removed by fishery			Escaped		
		walleye	sauger	whitefish	walleye	sauger	whitefish	walleye	sauger	whitefish
Constant recruitment[1]										
North basin	1979	185.88	472.38	667.25	40.03(22)	34.00(7)	196.15(29)	145.85	438.38	471.10
	1980	170.91	400.65	401.27	35.28(21)	27.71(7)	94.25(24)	135.63	372.94	306.42
	1981	118.37	363.96	372.89	28.53(24)	50.43(14)	96.94(26)	89.84	313.53	253.98
	1982	?	529.29	456.74	?	109.97(21)	124.25(27)	?	419.32	332.49
	1983	54.08	548.51	388.74	12.47(23)	151.29(28)	155.97(40)	41.61	397.22	232.77
South basin	1979	177.55	199.94		58.72(33)	92.52(46)		118.83	107.42	
	1980	2.95	259.84		0.18(6)	57.05(22)		2.77	202.79	
	1981	2.28	230.75		0.09(4)	11.60(5)		2.19	219.15	
	1982	2.05	107.09		0.08(4)	3.37(3)		1.97	103.72	
	1983	289.07	223.65		44.09(15)	30.62(14)		244.98	193.03	
Variable recruitment[2]										
South basin	1979	729.87	1584.73		65.28(9)	616.86(39)		664.59	967.87	
	1980	98.56	1373.42		2.22(2)	345.88(25)		96.34	1027.54	
	1981	38.02	1332.77		0.38(1)	31.51(2)		37.64	1301.26	
	1982	21.38	353.18		3.59(17)	13.50(4)		17.79	339.68	
	1983	1268.01	680.96		202.47(16)	174.61(26)		1065.54	506.35	

1. for each cohort, N_o = 1000 newborn fish
2. for each cohort, N_o = (predicted trawling CUE x 1000) + 1000

Table 29. Concomitant effects of changes in the fishery and environment on observed trawl catches of yoy walleyes and saugers from the south basin of Lake Winnipeg.

Species	Year	Trawl CUE			Escaped spawning biomass (kg)*	Warming rate (°C day^{-1})	Mean May flow rate of all rivers (m^{3}sec^{-1})
		Observed	Predicted	Residual			
Walleye	1979	2.5789	2.5669	0.0120	664.59	0.319	973
	1980	0.4253	0.4248	0.005	96.34	0.239	211
	1981	0.3185	0.0478	0.2707	37.64	0.198	82
	1982	1.0074	1.1502	0.1428	17.79	0.163	320
	1983	2.700	?	?	1065.54	?	230
Sauger	1979	8.0632	8.0522	0.0110	967.87	0.319	973
	1980	0.1034	0.1029	0.0005	1027.54	0.239	211
	1981	0.3778	0.1291	0.2487	1301.26	0.198	82
	1982	0.8015	0.9327	0.1312	339.68	0.163	320
	1983	0.4200	?	?	506.35	?	230

*from the variable recruitment model, Table 28.

These crude estimates of escaped female spawning biomass aid in explaining some of the discrepancies between observed and predicted trawl catches of juvenile walleyes and saugers in southern Lake Winnipeg (Table 29). The mean May flow rate of all four rivers was used to clarify the flow rate effect. From 1979 to 1981, the escaped south basin walleye spawning biomass, warming rates and flow rates all declined. These decreases were reflected in the trawl catches of yoy walleyes. In 1982, spawning biomass declined further as did the warming rate but flow rates increased dramatically. The 1982 spawning biomass decrease produced an observed catch of yoy walleyes that was lower than the value predicted strictly as a function of warming and flow rtes. In 1983, the highest spawning walleye biomass produced the highest trawl catches of yoy walleyes. Water temperatures were not recorded in 1983 but flow rates were relatively high. Using the same reasoning, the large 1981 discrepancy between observed and predicted sauger yoy catches can be attributed to the large 1981 spawning biomass. In 1982, the observed trawl catch of yoy saugers was less than the predicted value because the spawning biomass was low. The models that predict trawl catches of yoy fish as a function of warming rates and flow rates predict highly suspect values given extremely high or low values of the independent variables.

More annual estimates of escaped female spawning biomass, warming rates and flow rates are required to quantify the predictive model but it appears that catches of juvenile walleyes and saugers are a function of the size of the spawning stock as well as warming rates and flow rates of rivers entering Lake Winnipeg (Appendix C).

Estimates of the mean number of eggs produced per kilogram of Lake Winnipeg female fish are: 24872.5 whitefish eggs kg^{-1} (Derksen, unpublished report), 50655 walleye eggs kg^{-1} (Olynyk, unpublished data) and 76604.38 sauger eggs kg^{-1} (Moshenko, unpublished report). These mean values were constant over all sampled female body sizes and did not vary temporally. Thus the numbers of eggs deposited annually by females of each species is directly proportional to the numbers of individual females annually comprising the spawning stocks.

Cohort biomass of north basin walleye and sauger stocks are generally larger than those of their south basin counterparts. In the south basin, biomass tends to be concentrated in younger walleye and sauger age classes. The age distribution of north basin whitefish cohort biomass has remained more stable over time (Figs. 43-45). The interspecific and spatial differences in cohort biomass distributions are directly related to spatial differences in the nature of the fisheries occurring in each of the three major areas of Lake Winnipeg.

Fishery Influences

Historical trends in Lake Winnipeg's annual commercial catches (Table 30, Fig. 46) are typical of the characteristic pattern of stock response to overexploitation. The "fishing up" phase occurred from the late 1880's to 1940. From 1940 to 1969, catches of all species and "quota species" (walleyes, saugers and whitefish) declined irregularly due to the following increases in catchability and fishing effort:

a. the change from cotton to nylon gillnets during 1949-1955 increased catchability approximately three times (Lawler 1950).

b. in 1956, the legal mesh size allowed in the north basin was reduced from 5.25 to 5 inches. Kooyman (1955) estimated that this mesh size reduction increased catchability 1.5 times.

c. the length of the fishing season increased during the 1950's from 53 to 69 days.

d. in 1959, the daily gillnet yardage allowance for each north basin fisherman increased from 5000 to 8000 yards.

e. trap nets were used by some fishermen prior to the 1969 collapse of the fishery.

f. some fishermen illegally used smaller mesh gillnets (Hewson 1959).

Table 30. Historical yields and landed values of the Lake Winnipeg commercial fisheries, 1931 - 83.

Year	Catch (kg)					Landed value
	All species	Whitefish	Walleye	Sauger	Other species	($)
1931	3783777	1634833	1039543	699576	409775	389008
1932	4669553	2103762	1054376	866089	645326	426338
1933	5726378	2417693	1326123	1493861	488770	542795
1934	5971136	1777357	1663142	1708637	822000	551816
1935	5020043	1139923	1387267	1462064	1030789	497263
1936	6510049	303181	1900688	2964181	1341999	601850
1937	6764106	929502	1891299	3280471	662835	774920
1938	8406701	952136	1946864	4326047	1181654	709869
1939	7091147	920430	1466510	3921170	783037	688693
1940	9931497	1588254	1787608	4034523	2521112	1207042
1941	9145376	1819813	1635670	4641475	1048388	1401099
1942	8024186	1876784	1252505	3446168	1448729	1612446
1943	8244995	1695529	1625947	2893693	2029826	2056393
1944	6238483	1069027	2171347	2270774	727335	1306569
1945	7407300	1234316	2282885	1724604	2165496	2104586

Table 30, cont'd.

Year	Catch (kg)					Landed value
	All species	Whitefish	Walleye	Sauger	Other species	
1946	6490545	1098102	223887	1798539	1355017	1884507
1947	7456198	815151	2194798	1618735	2827514	1839451
1948	7460461	694858	2460739	1789422	2515442	1757565
1949	7852048	1097376	232695	315603	1275094	1821951
1950	8313896	1601862	2534039	2160234	2017761	2561050
1951	8513703	1243887	2701914	1701425	2866477	2529857
1952	7541019	1166685	2348883	1658833	2366618	2009858
1953	5365545	836833	2274721	995363	1258628	1513355
1954	6650073	978580	1966187	1004390	2700916	1659666
1955	796528	987834	2182097	1398244	3401354	1761893
1956	6275859	748382	1773501	1455034	2298943	1505981
1957	5650026	838828	1296775	1826345	1697978	1417096
1958	5830205	733141	998901	1959156	2139006	1734935
1959	4412230	848445	523491	116542	1874652	1479305
1960	4547173	507933	616886	1629667	1792688	1625833
1961	4352310	632399	957670	1152442	1609800	1267364

Table 30, cont'd.

Year	Catch (kg)					Landed value
	All species	Whitefish	Walleye	Sauger	Other species	
1962	4736185	758225	1271601	1361140	1345219	1727845
1963	4730107	597200	924331	1903183	1305394	1860995
1964	4402659	840189	670455	1468188	1423827	1617729
1965	4011481	691502	395487	1421785	1502706	1770891
1966	3657588	565176	319511	1412802	1359099	1721976
1967	2901812	641017	270477	1016047	966107	9077440
1968	3606876	374168	354392	1647448	1230868	1141679
1969	2584479	341963	389137	922743	930636	1221160
1970–71	mercury closure					
1972	3207080	713138	833476	1306392	354074	2607479
1973	3506905	748564	839237	1361230	557873	2896827
1974	3558561	740524	831756	1161529	824753	2844204
1975	3786198	828011	1014982	1225020	718186	3434072
1976	3505491	779124	1212934	1130189	383244	5209052
1977	4089140	1059435	1404730	1231539	393536	5132152
1978	4162435	1447486	1150518	1180125	384307	5277824

Table 30, cont'd.

Year	Catch (kg)					Landed value
	All species	Whitefish	Walleye	Sauger	Other species	
1979	4471997	1535404	1197072	1117418	622102	6879690
1980	5037160	1578083	1124259	1757056	577762	8563871
1981	5330361	1477650	1758447	1528419	565844	9935792
1982	4955463	1429448	1863063	1226763	436188	6963800
1983	5150238	1448059	1408307	2010814	283058	8871672

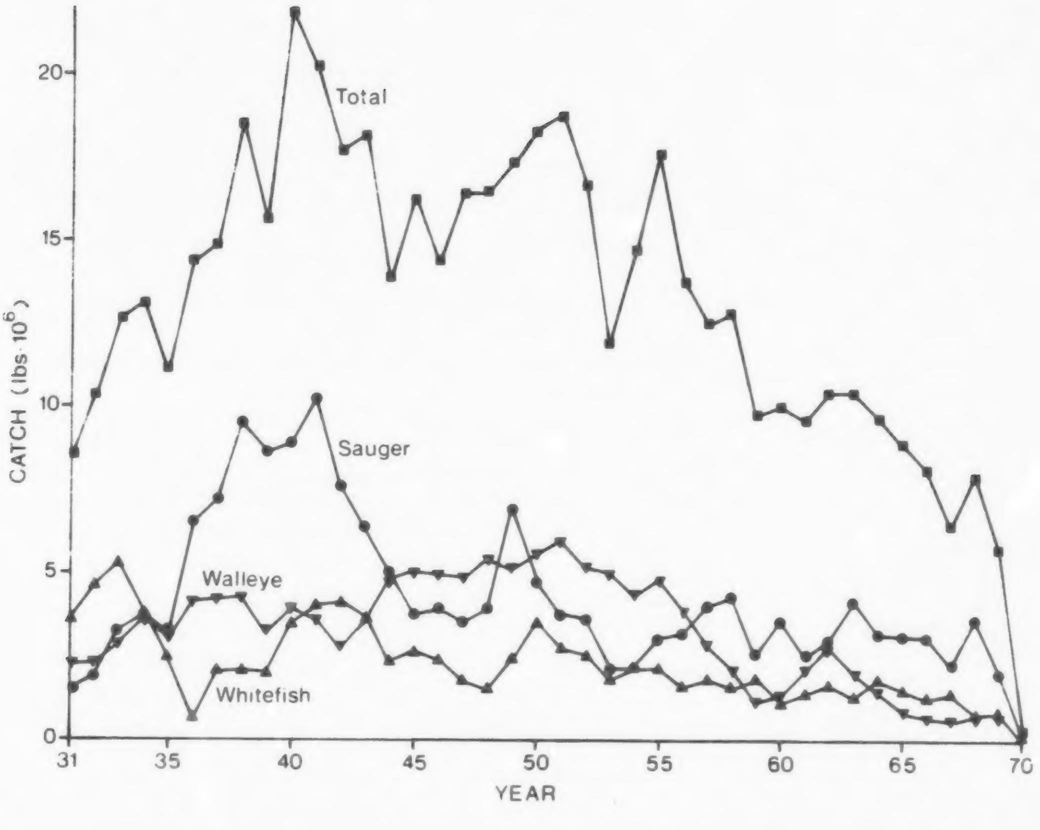


Fig. 46. Total and species specific commercial catches (annual marketed weight) from Lake Winnipeg, 1931-70.

Continuing overexploitation from 1949-1969 led to an economic collapse of the Lake Winnipeg fishery in 1969. Excessive amounts of mercury in walleyes and saugers resulted in a short fishing moratorium from 1970-1971. Since 1972, catches of all species have been slowly increasing (Fig. 46). Recent trends in catch densities (kg ha^{-1}) indicate that walleyes are the prime target species and that saugers and walleyes tend to change dominance in the commercial catches every one or two years (Table 31). Landed value densities (\$ ha^{-1}) have increased dramatically since the mercury closure (Table 31).

Recent Changes in Management Regulations

Three seasonal fisheries are allowed on Lake Winnipeg during each year. The summer fishery encompasses all areas of the lake and begins in June. The duration of the summer fishery varies between 40 and 69 days depending on location of the management zone (Table 32). In 1980, the change from the imperial to the metric measurement system resulted in an increase in the maximum amount of gillnets each fishermen can set each day. Summer quotas and numbers of summer fishermen have increased in most of the management zones (Table 32).

The fall fishery commences in September and lasts about two months. From 1972-1980, the fall fishery was concentrated in the south basin and channel areas of the lake. The most notable change in the fall

Table 31. Historical yields densities and landed value densities of the Lake Winnipeg commercial fisheries, 1931 - 83.

Year	Catch density (kg ha^{-1})					Landed value density
	All species	Whitefish	Walleye	Sauger	Other species	(\$ ha^{-1})
1931	1.59	0.69	0.44	0.29	0.17	0.16
1932	1.97	0.89	0.44	0.36	0.27	0.18
1933	2.41	1.02	0.56	0.63	0.21	0.23
1934	2.51	0.75	0.70	0.72	0.35	0.23
1935	2.11	0.48	0.58	0.62	0.43	0.21
1936	2.74	0.13	0.80	1.25	0.57	0.25
1937	2.85	0.39	0.80	1.38	0.28	0.33
1938	3.54	0.40	0.82	1.82	0.50	0.30
1939	2.99	0.39	0.62	1.65	0.33	0.29
1940	4.18	0.67	0.75	1.70	1.06	0.51
1941	3.85	0.77	0.69	1.95	0.44	0.59
1942	3.38	0.79	0.53	1.45	0.61	0.68
1943	3.47	0.71	0.68	1.22	0.85	0.87
1944	2.63	0.45	0.91	0.96	0.31	0.55

Table 31, cont'd.

Year	Catch density (kg ha^{-1})					Landed value density
	All species	Whitefish	Walleye	Sauger	Other Species	(\$ ha^{-1})
1945	3.12	0.52	0.96	0.73	0.91	0.89
1946	2.73	0.46	0.94	0.76	0.57	0.79
1947	3.14	0.34	0.92	0.68	1.19	0.77
1948	3.14	0.29	1.04	0.75	1.06	0.74
1949	3.31	0.46	0.98	1.33	0.54	0.77
1950	3.50	0.67	1.07	0.91	0.85	1.08
1951	3.58	0.52	1.14	0.72	1.21	1.07
1952	3.18	0.49	0.99	0.70	1.00	0.85
1953	2.26	0.35	0.96	0.42	0.53	0.64
1954	2.80	0.41	0.83	0.42	1.14	0.70
1955	3.36	0.42	0.92	0.59	1.43	0.74
1956	2.64	0.32	0.75	0.61	0.97	0.63
1957	2.38	0.35	0.55	0.77	0.71	0.60
1958	2.45	0.31	0.42	0.82	0.90	0.73
1959	1.86	0.36	0.22	0.49	0.79	0.62

Table 31, cont'd.

Year	Catch density (kg ha^{-1})					Landed value density
	All species	Whitefish	Walleye	Sauger	Other species	(\$ ha^{-1})
1960	1.91	0.21	0.26	0.69	0.75	0.68
1961	1.83	0.27	0.40	0.49	0.68	0.53
1962	1.99	0.32	0.54	0.57	0.57	0.73
1963	1.99	0.25	0.39	0.80	0.55	0.78
1964	1.85	0.35	0.28	0.62	0.60	0.68
1965	1.69	0.29	0.17	0.60	0.63	0.75
1966	1.54	0.24	0.13	0.60	0.57	0.73
1967	1.22	0.27	0.11	0.43	0.41	0.41
1968	1.52	0.16	0.15	0.69	0.52	0.48
1969	1.09	0.14	0.16	0.39	0.39	0.51
1970 - 71	mercury closure					
1972	1.35	0.30	0.35	0.55	0.15	1.10
1973	1.48	0.32	0.35	0.57	0.23	1.22
1974	1.50	0.31	0.35	0.49	0.35	1.20
1975	1.59	0.35	0.43	0.52	0.30	1.45

Table 31, cont'd.

Year	Catch density (kg ha^{-1})					Landed value density
	All species	Whitefish	Walleye	Sauger	Other species	(\$ ha^{-1})
1976	1.48	0.33	0.51	0.48	0.16	2.19
1977	1.72	0.45	0.59	0.52	0.17	2.16
1978	1.75	0.61	0.48	0.50	0.16	2.22
1979	1.88	0.65	0.50	0.47	0.26	2.90
1980	2.12	0.66	0.47	0.74	0.24	3.61
1981	2.24	0.62	0.74	0.64	0.24	4.18
1982	2.09	0.60	0.78	0.52	0.18	2.93
1983	2.17	0.61	0.59	0.85	0.12	3.74

Table 32. Regulatory changes in the summer fishery of the Lake Winnipeg management areas, 1970-83.

Area	Year	Quota (kg)	No. fishermen (regular & retired)	Minimum mesh size (mm)	Maximum daily amount of gillnet (meters)	Season length (days)
North basin						
Northend	70		--- mercury closure ---			
	71	7,711 kg. ind.	44	128 (5 in)	7315	69
	72-76	9,072 ind. 1,814 wa,sa	44	128	7315	69
	77	13,699 ind.	44	128	7315	69
	78,79	15,876 ind.	44	128	7315	69
	80-83	15,880 ind. 698,720 area	44	128	7400	69
Grand Rapids	70,71		--- mercury closure ---			
	72	136,078 area	61	108 (4.25 in)	1372	40
	73	136,078 area	59	108	1372	40
(Grand Rapids & Gull Bay)	74	136,078 area	59	108	1372	40
	75	90,718 area	41	108	1372	40
	76	90,718 area	49 + 5	108	1372	40
(Grand Rapids)	77	106,594 area	31 + 4	128 (5 in)	1372	40
	78	106,594 area 9,072 ind	31 + 4	128	1372	40
	79	106,594 area 9,072 ind	34 + 3	128	1372	40
	80	106,600 area	34 + 1	128	1400	57
	81	106,600 area	46 + 1	128	1400	57
	82	106,000 area	46 + 1	128 108 inshore	1400	57
	83	125,500 area 2,727 ind.	45 + 1	128 108 inshore	1400	57
Gull Bay	77	36,287 area	21 + 1	108	1372	40
	78	36,287 area	14 + 1	108	1372	40
	79	36,287 area	16 + 1	108	1372	40
	80	36,300 area	25 + 1	108	1400	57
	81	36,300 area	15	108	1400	57
	82	40,800 area	15	108	1400	57
	83	40,900 area 2,727 ind.	15	108	1400	57

Table 32, cont'd.

Area	Year	Quota (kg)	No. fishermen (regular & retired)	Minimum mesh size (mm)	Maximum daily amount of gillnet (meters)	Season length (days)
Big Black R.	70,71		--- mercury closure ---			
	72	36,287 area	23	128	1372	40
	73	36,287 area	28	108	1372	40
	74	36,287 area	25	108	1372	40
	75	36,287 area	18	108	1372	40
	76	36,287 area	18	108	1372	40
	77	50,802 area	25 + 1	108	1372	40
	78	50,802 area	23 + 2	108	1372	40
	79	50,802 area	24 + 4	108	1372	40
	80	50,900 area	24 + 4	108	1400	40
	81	50,900 area	26 + 5	108	1400	40
	82	50,900 area	28 + 5	108	1400	40
	83	50,900 area 2,000 ind.	28 + 7	108	1400	40
Sturgeon Bay	70,71		--- mercury closure ---			
	72	36,287 area	26	128 (4.25 in)	1372	40
	73	36,287 area	27	108	1372	40
	74	36,287 area	26	108	1372	53
	75	36,287 area	25	108	1372	40
	76	36,287 area	25	108	1372	40
	77	61,235 area 1973 ind.	27	108	1372	40
	78,79	61,235 area	27 + 1	108	1372	40
	80-83	61,290 area 53,460 max wa,sa (2270 ind. 1980 max. wa, sa)	27 + 1	108	1400	40
Narrows Berens R.	70,71		--- mercury closure ---			
	72	100,244 area	41	96 (3.75 in)	1372	40
	73-75	100,244 area	47	96	1372	40
	76	100,244 area	48	96	1372	40
	77	167,648 area	49	96	1372	40
	78,79	195,952 area 167,648 max. 4,082 ind.	48 + 1	96	1372	40

Table 32, cont'd.

Area	Year	Quota (kg)	No. fishermen (regular & retired)	Minimum mesh size (mm)	Maximum daily amount of gillnet (meters)	Season length (days)
	80-	196,320 area 168,000 max. wa,sa	49 + 1	96	1400	40
	81-83	196,320 area (4090 ind. 3500 max. wa,sa)	50	96	1400	40
Channel	70,71			--- mercury closure ---		
	72	194,138 area	89	77 (3 inch)	1372	40
	73	no quota listed	94	77	1372	40
	74-76	194,138 area	95	77	1372	40
	77	287,396 area 2,994 ind.	97	77	1372	40
	78	348,359 area 287,396 max, wa & sa	97 + 5	77	1372	40
	79	no change	93 + 5	77	1372	40
	80	348,480 area 288,000 max, wa & sa	96 + 3	96 in north channel 77 in south channel	1400	40
	81	no change	100 + 4	96,77		
	82	no chnage, 3,630 ind. 3,000 max. wa & sa	103 + 10	96,77		
	83	no change	103 + 11	96,77	1400	40
South basin South end	70,71			--- mercury closure ---		
	72	158,757	129	77	1372	40
	73	158,757	140	77	1372	40
	74	158,757	138	77	1372	40
	75	158,757	125	77	1372	40
	76	158,757	129	77	1372	40
	77	251,290	134 + 6	77	1372	40
	78	308,443	137 + 10	77	1372	40
	79	308,443	135 + 11	77	1372	40
	80	308,720	138 + 15	77	1400	40
	81	308,720	136 + 17	77	1400	40
	82	308,720	134 + 20	77	1400	40
	83	308,720	137 + 22	77	1400	40

fishery has been the creation of three new management zones in the north basin (Table 33).

The winter fishery commences after Lake Winnipeg freezes (usually in November) and most of the fishing activity occurs in December. The most notable changes in the winter fishery have been increases in quotas when individual quotas for commercial operators and commercial fishermen were equalized and the creation of the Berens River management zone in 1983 (Table 34).

The creation of new management zones has increased the amount of surface area exploited during each year. The fall fishery has been concentrated on the smallest surface area each year (Table 35).

Hatcheries at Grand Rapids and Sturgeon Bay have produced irregularly fluctuating amounts of whitefish and walleye fry that have been annually stocked in Lake Winnipeg. Annual maxima of hatchery-reared whitefish fry (Table 36) generally coincide with years in which warming and flow rates were high (Table 21). The high number of whitefish fry stocked in 1975 may be related to the maximum whitefish CUE that occurred in the north basin and channel five years later in 1980. The maximum number of walleye fry stocked in 1972 may be related to the 1976 channel and 1977 north basin maxima in walleye CUE values (Fig. 47).

Table 33. Regulatory changes in the autumnal fishery of the Lake Winnipeg management areas, 1970-83.

Area	Year	Quota (kg)	No. fishermen (regular & retired)	Minimum mesh size (mm)	Daily net allowance (meters)	Season length (days)
Channel						
North channel	70,71		--- mercury closure ---			
	72	1,360,777 (including south basin)	137	96	1372	56
	73		133	96	1372	56
	74	no change	137	96	1372	56
	75		139	96	1372	56
	76		136	96	1372	56
	77	518,184 (excluding south basin)	146+1	96	1372	71
	78	no change	147	96	1372	57
	79		542+20	96	1372	57
	80	518,160	555+24 whole lake total	96	1400	57
	81	no change	561+29	96	1400	57
	82	no change	563+28	96	1400	57
	83	no change	146+8	96	1400	60
South channel	77-79	670,591 area 3810 ind.	included in north channel	77	1372	57-61
	80-82	670,560 area		77	1400	57
	83	no change	177+12	77	1400	60

Table 33, cont'd.

Area	Year	Quota (kg)	No. fishermen (regular & retired)	Minimum mesh size (mm)	Daily net allowance (meters)	Season length (days)
South basin	70,71			--- mercury closure ---		
	72	1,360,777 (including channel)	395	77	1372	56
	73	no change	418	77	1372	56
	74		418	77	1372	56
	75		414	77	1372	56
	76		407	77	1372	56
			402+12	77	1372	56
	77	895,391 area 3810 ind	404+14	77	1372	61
	78	no change	546+15	77	1372	57
	79		542+20 whole	77	1372	57
		3810 ind	555+24 lake totals			
	81	no change	561+29	77	1400	57
	82		563+28	77	1400	57
	83		241+16	77	1400	60
North basin Grand Rapids	81	168,000 area	40+3	128 108 inshore	1400	47
	82	163,850 area (3620 ind., 1810 max. wa & sa)	44+2	108,128	1400	47
	83	no change	44+2	108,128	1400	39
Mossy Ranges	82	68,040 area	44	128	1400	38
	83	68,040	44	128	1400	38
Big Black R.	82	99,060 area	32+5	108,128	1400	37
	83	99,060	32+5	108,128	1400	37

Table 34. Regulatory changes in the winter fishery of the Lake Winnipeg management areas, 1970-83.

Area	Year	Quota (kg)	No fishermen (CO*, CF, or regular & retired)	Minimum mesh size (mm)	Daily net allowance (meters)	Season Length (days)
North basin North end	70,71	--- mercury closure ---				
	72	181,437 area	17CF,32CO	128	3658	150
	73	no change	17CF,31CO	128	3658	150
	74		17CF,30CO	128	3658	105
	75		14CF,31CO	128	3658	150
	76		20CF,28CO	128	3658	150
	77	312,298 area 6,373 ind.	47	108	3658	150
	78	403,017 area	47	128	3658	150
	79	312,298 area 6,373 ind.	45	128	3658	150
	80	312,310 area 6,650 ind.	48	128	3658	150
	81	no change	49	128	7400	150
	82		48	128	7400	150
	83	377,630 area 7,750 ind.	49+5	128	7400	150

Table 34, cont'd.

Area	Year	Quota (kg)	No fishermen (CO*, CF, or regular & retired)	Minimum mesh size (mm)	Daily net allowance (meters)	Season Length (days)
Sturgeon Bay	70,71		—— mercury closure ——			
	72	569,259 (whole lake)	8CF,12CO	108	3658	150
	73	no change	6CF,12CO	108	3658	119
	74,75	no change	8CF,12CO	108	3658	150
	76	no change	11CF,11CO	108	3658	150
	77	64,864 excluding all other zones 1814 CF, 4082 CO	13CF,10CO	108	3658	150
	78,79	no change	13CF,10CO	108	3658	150
	80	93,900	23	108	3658	150
	81	no change	23	108	3658	150
	82	218,000 area 4090 ind.	70	108	7400	150
	83	377,200 5450 ind. 4090 max. wa. sa.	69	108	7400	150

Table 34, cont'd.

Area	Year	Quota (kg)	No fishermen (CO*, CF, or regular & retired)	Minimum mesh size (mm)	Daily net allowance (meters)	Season Length (days)
South basin & Channel	70,71		— mercury closure —			
	72	569,259 all lake areas	100CF,64CO	77	3658	150
	73	no change	103CF,63CO	77	3658	119
	74		100CF,63CO	77	3658	150
	75		102CF,64CO	77	3658	150
	76		109CF,64CO	77	3658	150
	77	460,850 excluding all other zones 1814 CF, 4082CO	114CF,64CO	77	3658	150
	78	no change	113CF,58CO	77	3658	150
	79		109CF,58CO	77	3658	150
	80	715,750 area	177	77	3658	150
	81	no change	184	77	3658	150
	82		180	77	3658	150
	83		170+16	77	7400	150
Berens R.	1983	119,700	17+1	77	7400	150

* CO - commercial operator
CF - commercial fisherman
ind - individual quota
max.wa.sa. - maximum allowable weight of walleyes & saugers

Table 35. Changes in surface areas (hectares) of Lake Winnipeg's management zones from 1971-1983.

Management zone	Year														
	1971-1972			1973			1974			1975			1976		
	Summer	Fall	Winter	Summer	Fall	Winter	Summer	Fall	Winter	Summer	Fall	Winter	Summer	Fall	Winter
NORTH BASIN															
North end	1579888			1579888		1583366	1502465		1583366	1478724		1583366	1478724		1583366
Sturgeon Bay	46751		46751	46751		70420	46751		70420	46751		70420	46751		70420
Grand Rapids	27037		163830	27037			102514			94214			94214		
Gull Bay			304335							33987			33987		
Big Black R.	21075		78732	21075			21075			21075			21075		
Total	1674751		593648	1674751		1653786	1672805		1653786	1674751		1653786	1674751		1653786
CHANNEL															
Berens R.	46520	152581	152581	46520	152581	709958	46520	179692	709958	46520	179692	709958	46520	179692	709958
North Channel															
Total	46520	152581	152581	46520	152581		46520	179692		46520	179692		46520	179692	
SOUTH BASIN															
Channel	230308	556963	556963	230308	556963		244363	556963		244363	556963		244363	556963	
South end	326655			326655			326655			326655			326655		
Total	556963	556963	556963	556963	556963		571018	556963		571018	556963		571018	556963	

Table 35 continued

Management zone	Year 1977 Summer	 Fall	 Winter
NORTH BASIN			
North end	1478724		1583366
Sturgeon Bay	46751		70420
Grand Rapids	94214		
Gull Bay	33987		
Big Black R.	21075		
Total	1674751		1653786
CHANNEL			
Berens R.	46520	179692	709958
North Channel	47710		
Total	94230	179692	
SOUTH BASIN			
Channel	230308	230308	
South end	326655	326655	
Total	556693	556693	

Table 35 continued

Management zone	Year														
	1978-1979			1980			1981			1982			1983		
	Summer	Fall	Winter	Summer	Fall	Winter	Summer	Fall	Winter	Summer	Fall	Winter	Summer	Fall	Winter
NORTH BASIN															
North end	1478724		1580150	1478724		1580150	1401663		1580150	1401663		1580150	1401663		1413222
Sturgeon Bay	46751		70420	46751		70420	70420		70420	70420		70420	70420		70420
North Sturgeon															136768
Grand Rapids	94214			94214			94214			94214	206994		94214	206994	
Gull Bay	33987			33987			33987			33987			33987		
Mossy Ranges							48298			48298	48298		48298	48298	
Big Black R.	21075			21075			21075			21075	80390		21075	80390	
Total	1674751		1650570	1674751		1650570	1669657		1650570	1669657	335682	1650570	1669657	335683	1620410
CHANNEL															
Berens R.	46520	179692	709958	46520	179692	709958	46520	179692	709958	46520	179692	709958	46520	179692	69480
North Channel	47649			47649			47649			47649			91828		672810
Total	94169	179692		94169	179692		94169	179692		94169	179692		138348	179692	
SOUTH BASIN															
Channel	230308	230308		230308	230308		230308	230308		230308	230308		230308	230308	
South end	326655	326655		326655	326655		326655	326655		326655	326655		326655	326655	
Total	556963	556963		556963	556963		556963	556963		556963	556963		556963	556963	

Table 36. Numbers of fish fry stocked annually in Lake Winnipeg, 1970-83.

Year	No. stocked fry	
	Whitefish	Walleye
1970	70,569,500	7,800,000
1971	0	3,000,000
1972	0	23,000,000
1973	42,970,000	3,750,000
1974	29,000,000	0
1975	61,500,000	0
1976	0	12,000,000
1977	14,750,000	0
1978	1,500,000	4,862,000
1979	23,350,000	0
1980	41,500,000	0
1981	61,150,000	2,300,000
1982	2,579,725	0
1983	8,000,000	26,500,000

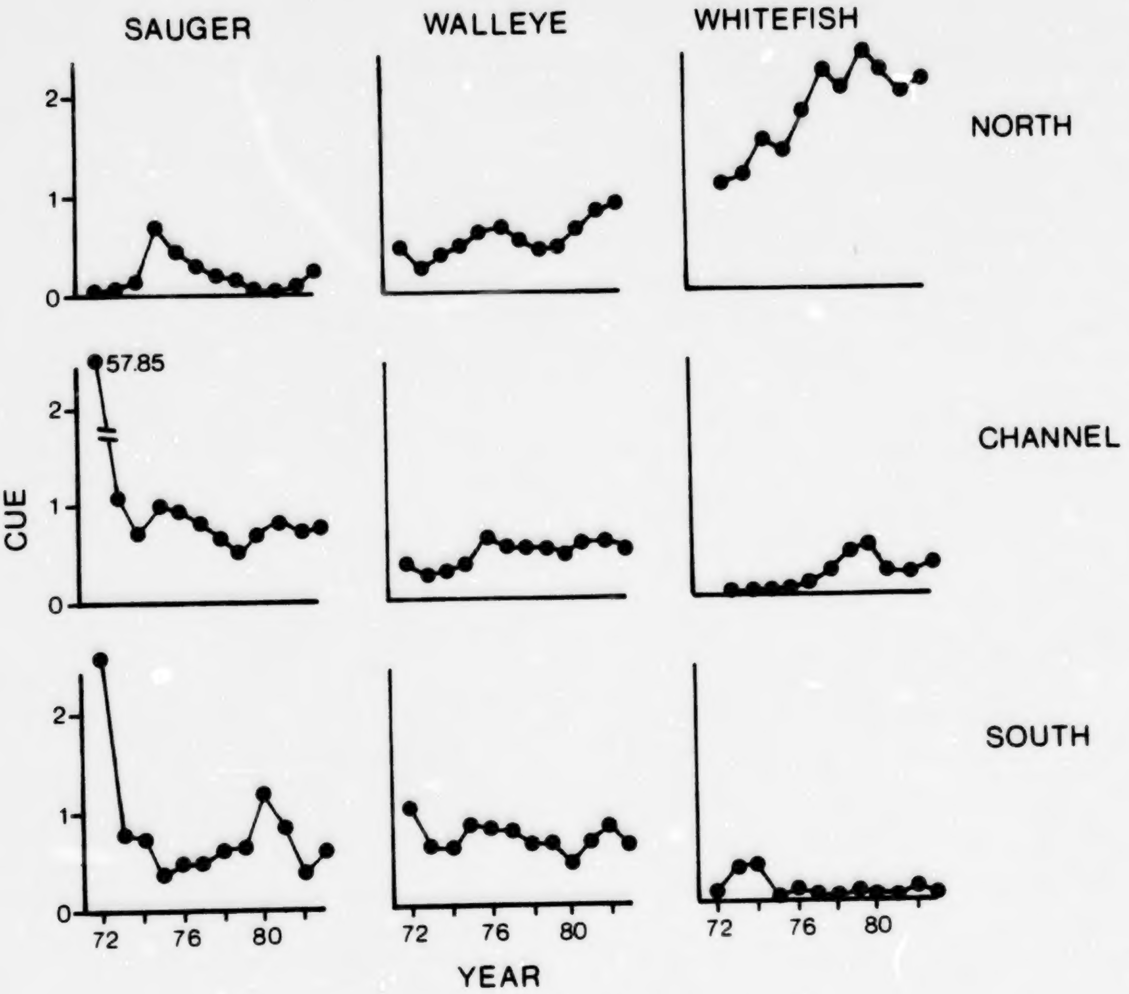


Fig. 47. Spatial and temporal distributions of walleye, sauger and whitefish CUE (kg delivery $^{-1}$) values from Lake Winnipeg's commercial fisheries.

Recent Trends in Commercial Fishery Yields

Temporal trends in commercial fishery CUE values are conceptually a function of stock abundance, the type and amount of fishing effort exerted on that stock and market value ($ unit weight^{-1}) of the species. The commercial fishery CUE values for the quota species exploited in each major area of Lake Winnipeg were derived from catch and effort data provided by the Freshwater Fish Marketing Corporation (FFMC) (Figs. 48,49, Table 37).

The north basin of Lake Winnipeg has been the historic fishing ground for whitefish. Recently, the northern whitefish stock has shifted southward into the northern reach of the channel area. Whitefish occur sporadically at very low abundances in southern Lake Winnipeg. This southerly shift is reflected in recent CUE changes of channel whitefish (Fig. 47). Whitefish CUE is higher in the north basin than in the channel since fishing effort is lower and larger (5-5.25 inch) meshes are used in the north basin.

Fishing effort directed at walleye and sauger stocks has remained lower in the north basin than in the channel and south basin (Fig. 48). Concomitant temporal changes in walleye CUE values from each major area (Fig. 47) imply that the northern walleye stock is larger than the channel and southern walleye stocks. Temporal changes in effort relative to sauger CUE values imply that saugers are most abundant in the channel area.

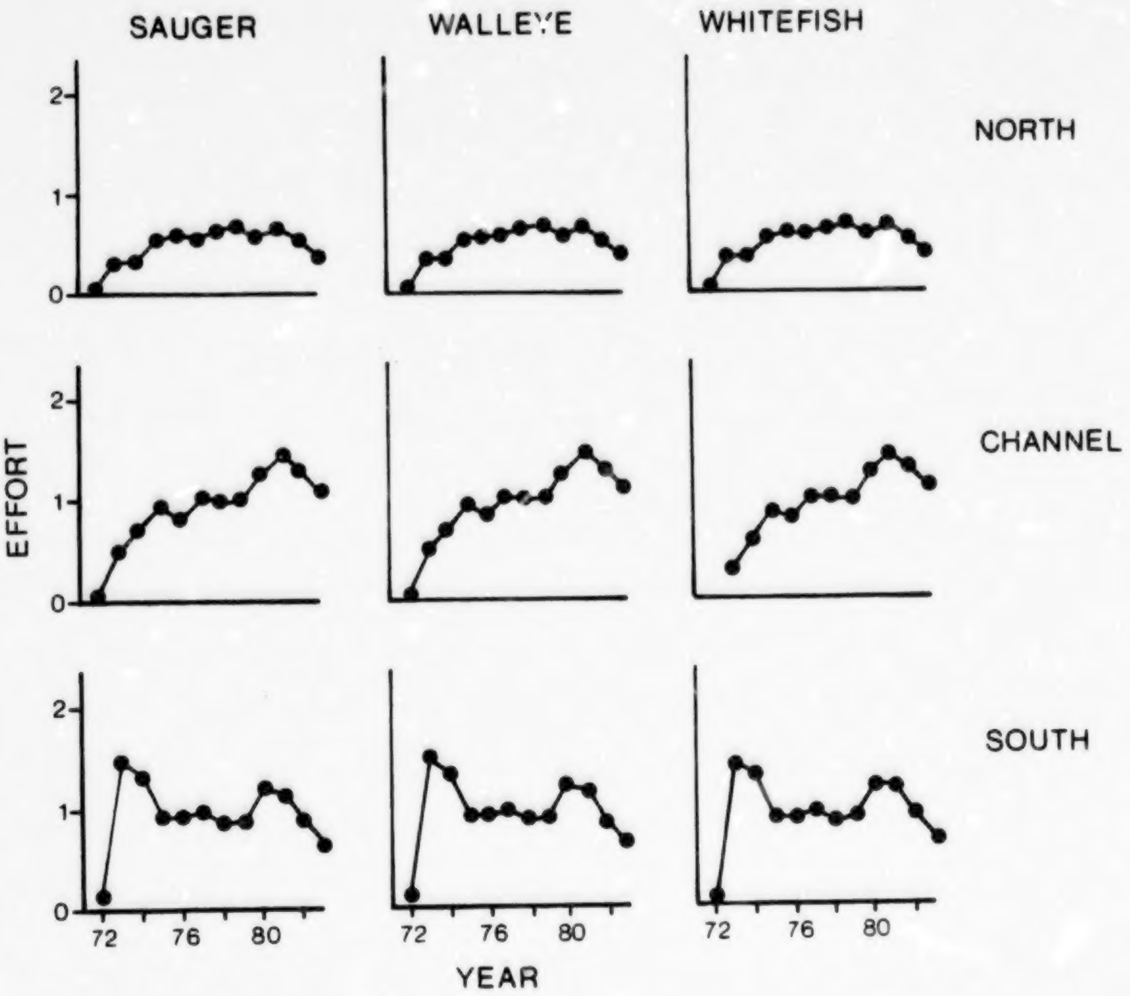


Fig. 48. Spatial and temporal distribution of fishing effort (no. deliveries x 10^4) on Lake Winnipeg.

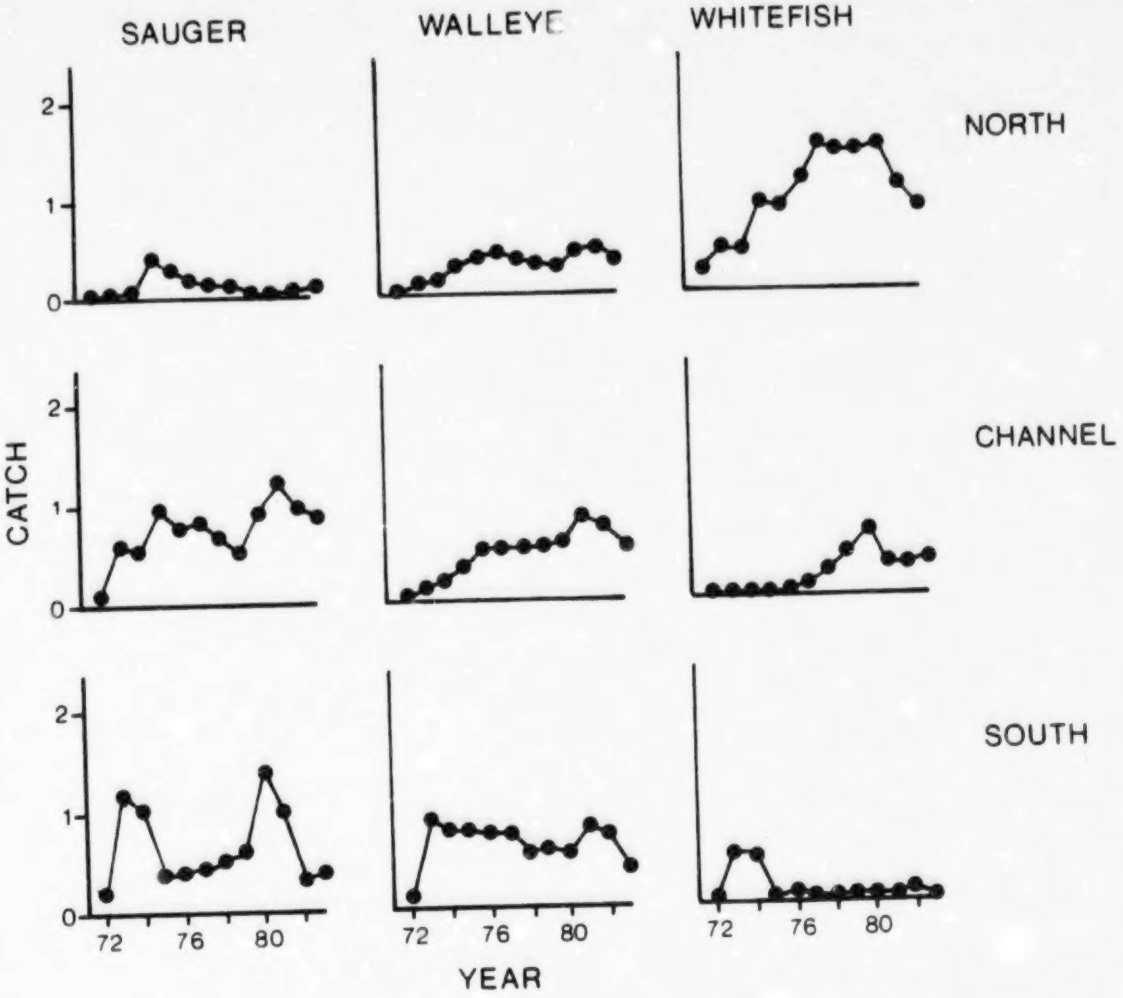


Fig. 49. Spatial and temporal distribution of walleye, sauger and whitefish commercial catches (kg x 10^6) from Lake Winnipeg.

Table 37. Commercial catches (kg), fishing effort (no. deliveries and CUE (kg delivery $^{-1}$) for walleyes, saugers and whitefish from the three major regions of Lake Winnipeg, 1972-83.

Species	Lake region	CUE	Year											
			1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983*
Walleye	North basin	Catch	19580	91074	138688	264384	366700	386364	335453	283289	252542	405895	435341	340828
		Effort	426	3445	3491	5504	5790	6306	6306	6726	5587	6400	5267	3693
		CUE	45.96	26.44	39.73	48.04	63.34	66.93	53.20	42.12	45.20	63.42	82.65	92.29
	Channel	Catch	4089	110154	190122	322717	502539	507961	491437	506102	552017	817912	737785	569101
		Effort	123	5039	7164	9478	8186	10242	9944	10006	12640	14472	12976	10980
		CUE	33.24	21.86	26.54	34.05	61.39	49.60	49.42	50.58	43.67	56.52	56.86	51.83
	South basin	Catch	94672	886748	760295	750456	712669	727853	528735	555871	528620	780620	684287	372359
		Effort	963	14736	13126	9047	9122	9474	8391	8801	11865	11620	8746	6324
		CUE	98.31	60.18	57.92	82.95	78.13	76.82	63.01	63.18	44.55	67.17	78.24	58.88
Sauger	North basin	Catch	647	19012	42296	373263	253855	160968	113833	101081	18473	14355	37457	84268
		Effort	426	2955	3111	5288	5800	5376	6311	6726	5587	6400	5267	3693
		CUE	1.52	6.43	13.59	71.40	43.77	29.94	18.04	15.03	3.31	2.24	7.11	22.82
	Channel	Catch	71158	569408	505769	936920	765824	832721	663837	504499	932543	1225219	929639	852388
		Effort	123	5039	7164	9478	8186	10242	9944	10006	12640	14472	12976	10980
		CUE	578.52	113.00	70.60	98.85	93.55	81.31	66.76	50.42	73.78	84.66	71.64	77.63
	South basin	Catch	243479	1174828	981839	322915	411329	448515	517661	548[illegible]1	1392600	987626	317917	362663
		Effort	963	14736	13126	9047	9122	9478	8391	[illegible]	11865	11620	8746	6324
		CUE	252.83	79.72	74.80	35.69	45.09	47.32	61.69	64.26	117.37	84.99	36.35	57.35
Whitefish	North basin	Catch	220389	382757	413783	858650	1070550	1448427	1375962	13175967	1453541	1049970	1059970	798297
		Effort	426	3445	3491	5452	5790	5773	6304	6726	5587	6400	5267	3693
		CUE	517.35	111.11	118.53	157.49	141.63	185.44	229.76	204.57	246.28	227.12	201.25	216.16
	Channel	Catch	-	1410	3297	14419	27948	99291	228540	414831	635080	281073	261802	314278
		Effort	-	3055	5811	8632	8006	9891	9922	9594	12640	14472	12976	10980
		CUE	-	0.46	0.57	1.67	3.49	10.04	23.03	43.24	50.24	19.42	20.18	28.62
	South basin	Catch	7484	479443	446728	12845	78911	33761	10785	58817	52266	32247	96818	21678
		Effort	6433	13924	12816	8548	8619	9167	8009	8706	11865	11620	8746	6324
		CUE	11.64	34.43	34.86	1.50	9.15	3.68	1.35	6.75	4.41	2.78	11.07	3.43

*summer fishery only

Since commercial catches of walleyes, saugers and whitefish are controlled by a common quota, the species specific values ($\$ \text{ kg}^{-1}$) to fishermen define "target" species (Appendix B). Walleyes are the most valuable fish, saugers are of intermediate value and whitefish are the least valuable fish in the Lake Winnipeg fishery. During any given year, the value of any of the quota species increases as a function of individual body size of the fish and the amount of pre-delivery processing that is performed by the fishermen (i.e., whole or "round" fish are worth less than dressed fish which, in turn, are worth less than headless dressed fish). Within any given year, the value of fish caught during the winter fishery is generally higher than that of fish caught in open water fisheries. This probably reflects the better quality of "winter fish" (less chance of spoiled flesh) as well as higher winter market demands.

A quadratic curve was fitted to a plot of annual catches of all fish species (reported by Manitoba Fisheries Branch) and their associated annual amounts of fishing effort estimated by the number of catch deliveres reported by the FFMC from 1973 to 1982 (Fig. 50). The equation describing this curve is:

$$Y = 20182339.9 + 1611.411X - 0.025X^2$$

where Y = annual commercial catch of all species (kg)

X = fishing effort (no. deliveries)

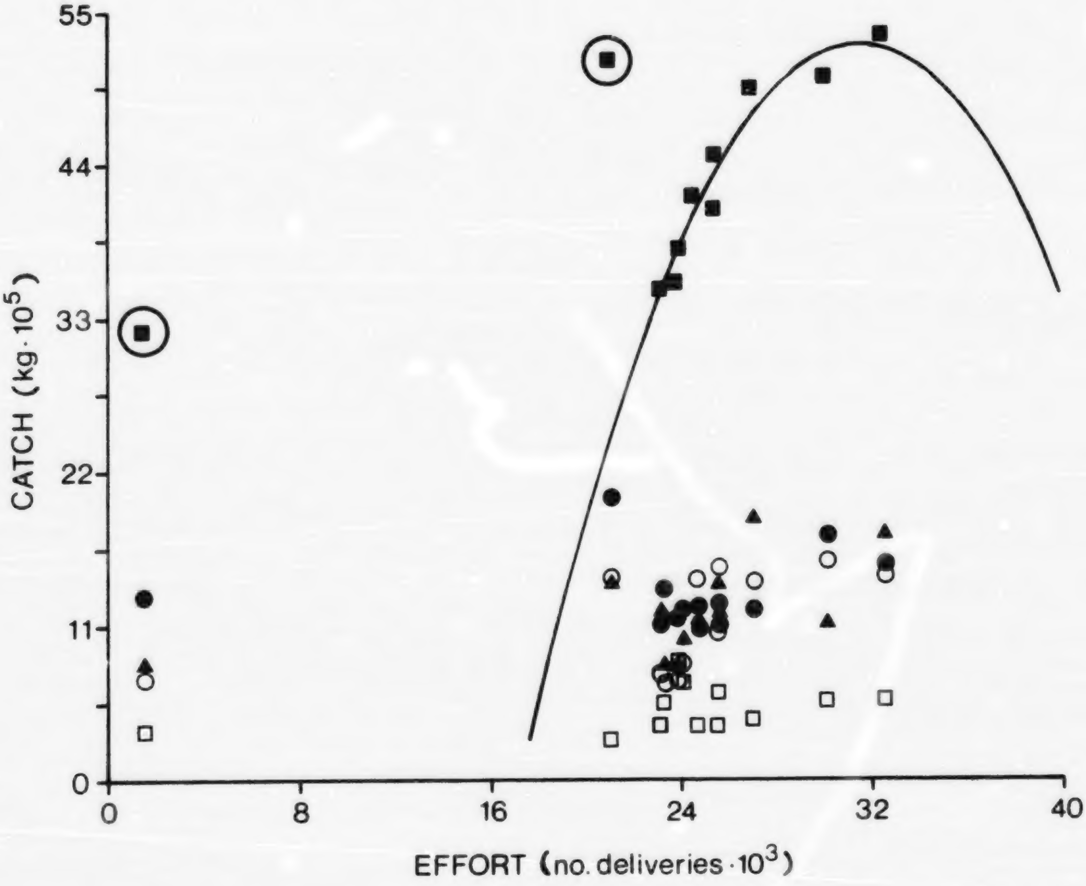


Fig. 50. Relationship of fishing effort and commercial catches of walleyes (▲), whitefish (○), saugers (●), non quota species (□) and all species (■) from Lake Winnipeg. Circled points were deleted from fitting of the parabola.

An analysis of variance indicated that the curve was significant at $P = 0.05$ (test $F = 67.37$; d.f. = 2,7; $r = 0.975$). According to this equation, the maximum $Y= 5280547$ occurs when $X = 31600$ deliveries. This maximum yield value is equivalent to 2.22 kg $ha^{-1}year^{-1}$. Minor discrepancies exist between the annual commercial catches reported by Manitoba Fisheries Branch (Table 38) and the annual commercial catches reported by the FFMC (Table 37). Annual catch and effort estimates for 1972 and 1983 were omitted from the above analysis since 1972 was the first year that the fishery was allowed to operate after the mercury closure and the 1983 effort estimate was incomplete.

Annual, whole lake commercial catches of the quota species are compared to annual, whole lake quotas on Table 39. Annual quota densities increased from 1.5 to 2.3 kg ha^{-1} while annual yield densities increased from 1.2 to 2 kg ha^{-1} from 1972 to 1983. Recently, yields approached quotas in 1980 and 1981. Since 1981, the annual quota - yield differences have been increasing.

Attempts to estimate annual yield densities and quota densities for most individual management zones were confounded by quotas that were common to more than one zone and incomplete data in many cases (Tables 32-34). This analysis did provide a reliable description of temporal changes in yield and quota densities of the south basin management zone (Table 40). From 1972 to 1982, quota densities remained high and relatively stable relative to yield densities of walleyes and saugers.

Table 38. Lake Winnipeg's commercial catches reported by Manitoba Fisheries Branch and effort (no. deliveries) reported by FFMC.

Year	Effort (no. deliveries)	Commercial catch (kg)				
		All species	Whitefish	Walleye	Sauger	Non quota species
1972	1512	3207080	713138	833476	1306392	354074
1973	23220	3506905	748564	839237	1361230	557873
1974	23781	3558561	740524	831756	1161529	824753
1975	24029	3786198	828011	1014982	1225020	718186
1976	23108	3505491	779124	1212934	1130189	383244
1977	25489	4089140	1059435	1404730	1231539	393536
1978	24646	4162435	1447486	1150518	1180125	384307
1979	25533	4471997	1535404	1197072	1117418	622102
1980	30092	5037160	1578083	1124259	1757056	577762
1981	32492	5330361	1477650	1758447	1528419	565844
1982	26989	4955463	1429448	1863063	1226763	436188
1983	20997*	5150238	1448059	1408307	2010814	283058

* from summer fishery

Table 39. Annual, whole lake quotas and commercial catches of quota species (walleyes, saugers and whitefish).

Year	Quota	Yield of quota species[a]	Surface density (kg ha $^{-1}$)[b]	
			Quota	Yield of quota species
1972	3,577,543-4,553,237[c]	2,853,006	1.506-1.917	1.201
1973	3,577,543-4,553,237[c]	2,949,031	1.506-1.917	1.242
1974	3,577,543-4,553,237[c]	2,733,809	1.506-1.917	1.151
1975	3,527,647-4,489,733[c]	3,068,013	1.485-1.890	1.292
1976	3,527,647-4,489,733[c]	3,122,247	1.485-1.890	1.315
1977	4,481,795	3,695,704	1.887	1.556
1978	4,577,595	3,778,129	1.927	1.591
1979	4,577,595	3,849,894	1.927	1.621
1980	5,013,360	4,459,398	2.111	1.878
1981	5,013,360	4,764,516	2.111	2.006
1982	5,349,760	4,519,274	2.253	1.903
1983	5,474,710	4,867,180	2,305	2.049

[a] from Table 38

[b] surface area = 2,375,000 ha (from Brunskill, 1980)

[c] from 1972-1976, the quota was originally stated in marketed (headless dressed, dressed) weight; species conversion factors (market weight to round weight) ranged from 1.1 to 1.4.

Table 40. Annual surface densities of walleye and sauger yields and quotas of Lake Winnipeg's south basin management zone.

Year	No. fishermen	Surface density (kg ha^{-1})[a]							
		Commercial yield[b]				Quota[c]			
		Walleye	Sauger	Σ	Σ fisherman^{-1}	Summer	Fall	Winter	Σ
1972	395	0.290	0.745	1.035	0.0026	0.486	4.166	1.743	6.395
1973	418	2.715	3.597	6.312	0.0151	0.486	4.166	1.743	6.395
1974	414	2.328	3.006	5.334	0.0129	0.486	4.166	1.743	6.395
1975	407	2.297	0.989	3.286	0.0081	0.486	4.166	1.743	6.395
1976	414	2.182	1.259	3.441	0.0083	0.486	4.166	1.743	6.395
1977	418	2.228	1.373	3.601	0.0086	0.769	2.741	1.411	4.921
1978	561	1.407	0.572	1.979	0.0035	0.944	2.741	1.411	5.096
1979	562	1.702	1.678	3.380	0.0060	0.944	2.741	1.411	5.096
1980	579	1.618	4.263	5.881	0.0102	0.945	2.741	2.191	5.877
1981	590	2.390	3.023	5.413	0.0092	0.945	2.741	2.191	5.877
1982	591	2.090	0.973	3.063	0.0052	0.945	2.741	2.191	5.877

a. surface area of this management zone = 326,655ha (from Table 35)
b. from Table 37
c. from Tables 32-34.

Whitefish catches were not included since most of the whitefish that are reported as south basin catches are caught in the extreme northern part of the south basin and comprise an extremely small part of the catches. Relatively high yields of walleyes and saugers in 1980 and 1981 are presumably the result of strong cohorts produced in 1974 and 1975 as well as increasing effort. This becomes especially evident when the total yield densities were corrected for changes in the numbers of fishermen (Table 40). During 1974-1976, relatively low numbers of fishermen produced relatively low yields of walleyes and saugers. This presumably increased the biomass of escaped female spawners whose eggs had a relatively high hatching success since flow and warming rates were relatively high (see Tables 21,29). These strong cohorts were recruited to the commercial fishery in 1980 and 1981, resulting in relatively high yield densities during those years (Table 40).

The imposition of annual quotas does not appear to be related to annual fluctuations in commercial yields from the entire lake or from the south basin management zone.

Since 1972, season lengths and minimum mesh sizes have not changed appreciably within individual management zones. Daily net allowances changed from 1372 m to 1400 m per fishermen per day in most of the summer and fall management zones (Tables 32,33). Substantial increases in daily net allowances occurred in the winter management zones in 1980, 1982 and 1983 (Table 34). The most important temporal changes in regulations that have occurred since 1972 are:

a. increases in numbers of new fishermen and increases in numbers of "retired" fishermen

b. creation of additional seasonal fisheries (fall fisheries at Grand Rapids, Mossy Ranges and Big Black River, winter fishery at Berens River)

c. increases in the amount of surface area that fishermen can exploit in the inshore areas of the north basin (Table 35)

d. increases in individual quotas

The relaxation of these restraints is reflected by increases in fishing effort (measured by numbers of deliveries) and increasing whole lake yields.

The most important spatial change in Lake Winnipeg's fishery regulation is the south-north gradient of minimum mesh size and fishing effort. South basin fishermen are allowed to use three inch mesh nets, channel fishermen are allowed to use 3.75 inch mesh nets and north basin fishermen are allowed to use 4.25, 5.0 and 5.25 inch mesh nets. During the 1970's, relatively high numbers of fishermen were concentrated in the south basin and channel open water fisheries. Recently, numbers of fishermen have become evenly distributed among the three major lake areas:

	summer 1983	fall 1983	winter 1983
North basin	168	127	123
Channel	164	343	204
South basin	159	257	

This trend is due to increasing numbers of fishermen allowed access to north basin fisheries and a tendency for south basin fishermen to move to the more productive areas in the channel.

Annual descriptions of species specific changes in body sizes, ages, CUE (in terms of numbers and biomass) and frequencies of mature fish as a function of mesh size in each major lake area were provided in the annual stock assessment reports (Lysack 1980-1984). Minor annual variations in mesh size distibutions of these parameters are due to sampling place and sampling time variations as well as mixing of stocks especially in the channel area. The south-north increase in mesh sizes of commercial gillnets is directly related to the amounts of compensatory responses displayed by walleye and sauger stocks in each mesh size zone. Pre-recruited walleyes and saugers in Lake Winnipeg's south basin grow and mature faster than their north basin counterparts. They are removed by three inch mesh nets and consequently their L_∞ values are small. North basin walleyes and saugers grow and mature slower but attain a larger L_∞ because they are exploited with larger mesh nets. Spatial differences in the amounts of compensatory growth responses caused by the difference in commercial meshes are depicted for walleyes (Fig. 51) and saugers (Fig. 52). A compensatory response of growth has not occurred in the north basin whitefish stock (Fig. 53) since it has been exploited at a relatively constant effort (44 fishermen) with relatively large (5.0-5.25 inch) mesh gillnets (see "north end", Table 32).

Annual estimates of channel walleye and sauger stock parameters were generally intermediate to those of the northern and southern stocks (Lysack 1980-1984) since the channel stocks are exploited with an intermediate (3.75 inch) mesh. Catch curves of channel walleyes and saugers (see Figs. 61-64, Lysack 1983) display characteristics of both north basin and south basin catch curves. Presumably, channel stocks are less discrete and are comprised of annually varying "mixes" of northern and southern individuals.

Serial deteriorations of south basin walleye and sauger catch curves occur between the summer and fall fisheries (see Figs. 62 and 64, Lysack 1983) and within any season (see Figs.51 and 57, Lysack 1982). These deteriorations and the continuing reliance of the south basin fishery on young, immature fish lead to the hypothesis that major southward migrations of north basin walleyes and saugers are supporting the south basin fishery. If the north basin is acting as a source of walleyes and saugers for the entire lake, then the recent relaxation of management regulations in the north basin will adversely affect future commercial yields of the entire lake.

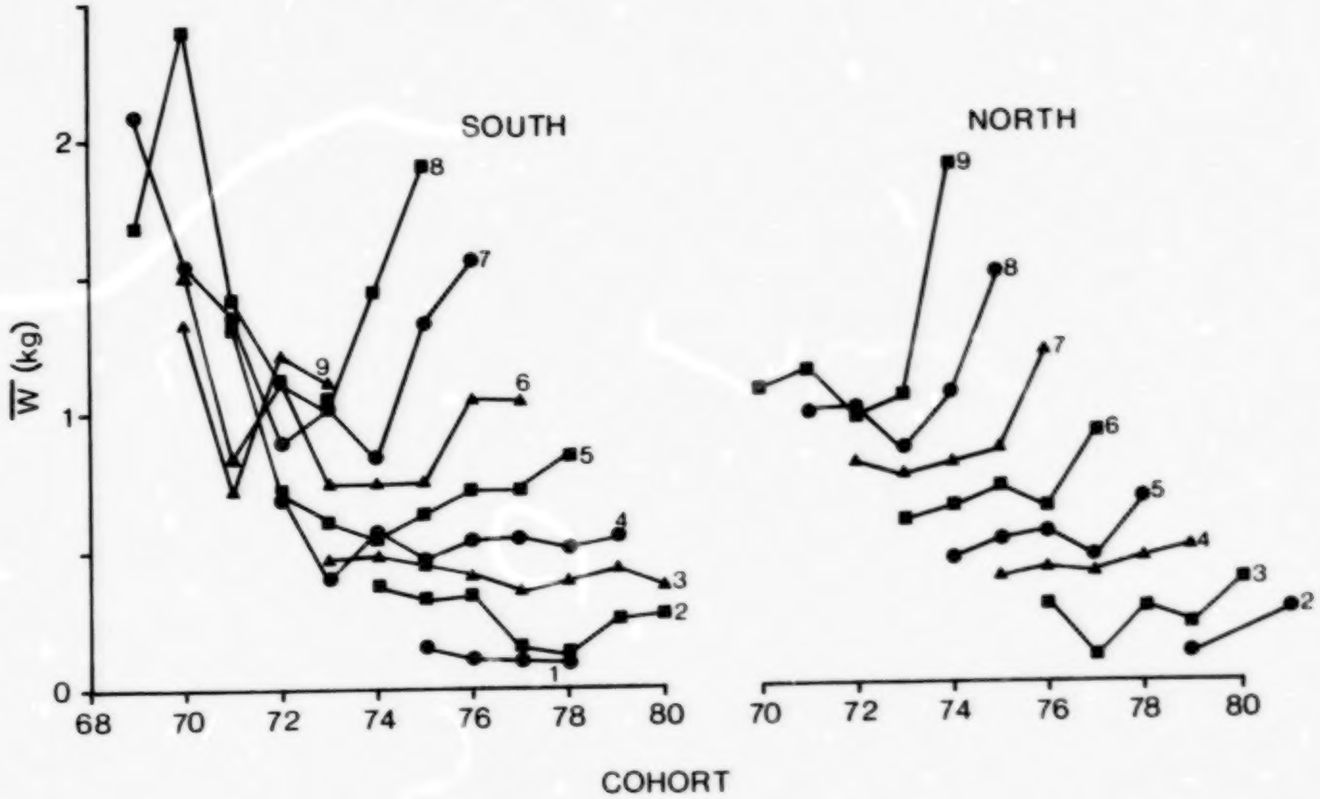


Fig. 51. Compensatory responses in growth ($\bar{W}$ = mean individual body weight) of walleye age groups in southern and northern Lake Winnipeg.

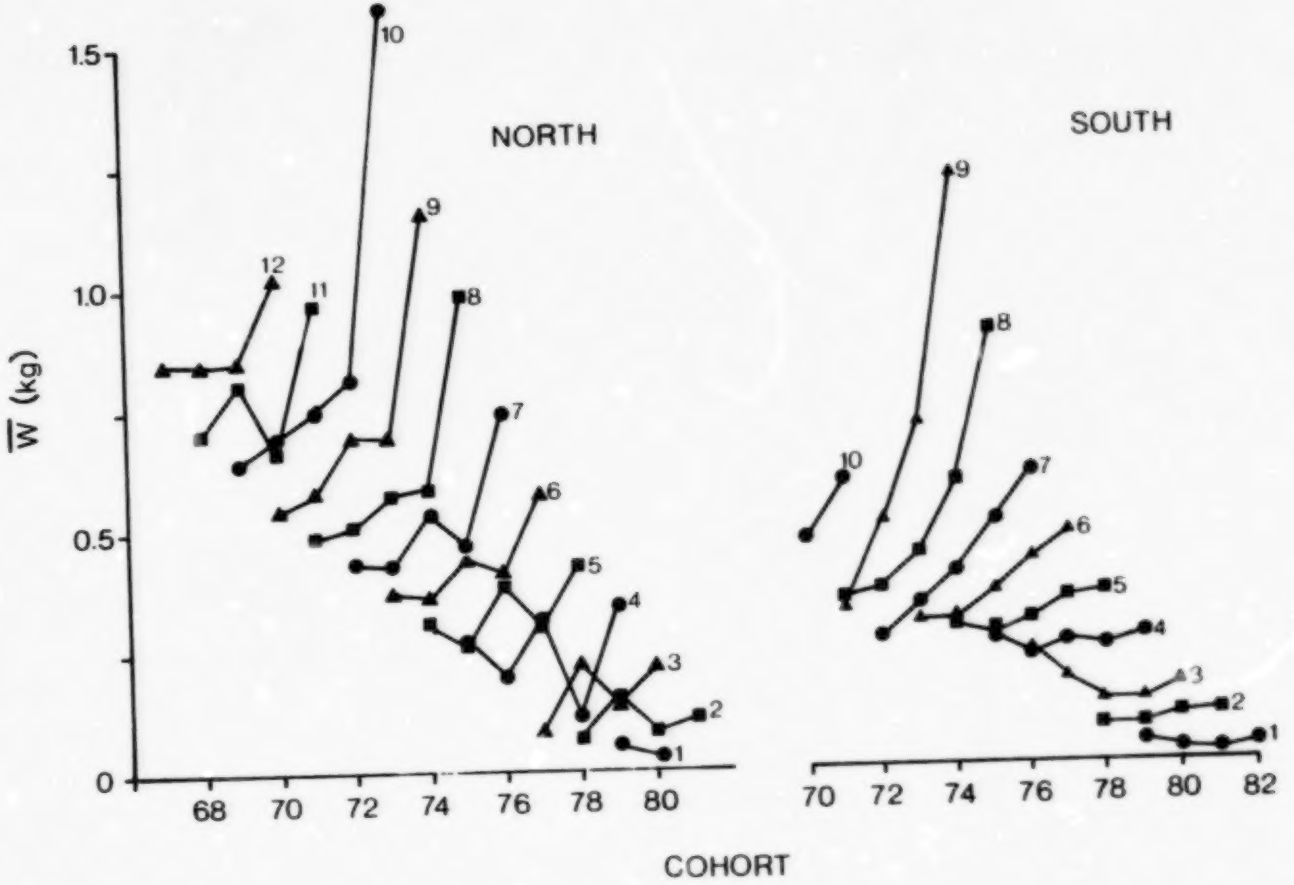


Fig. 52. Compensatory responses in growth ($\bar{W}$ = mean individual body weight) of sauger age groups in northern and southern Lake Winnipeg.

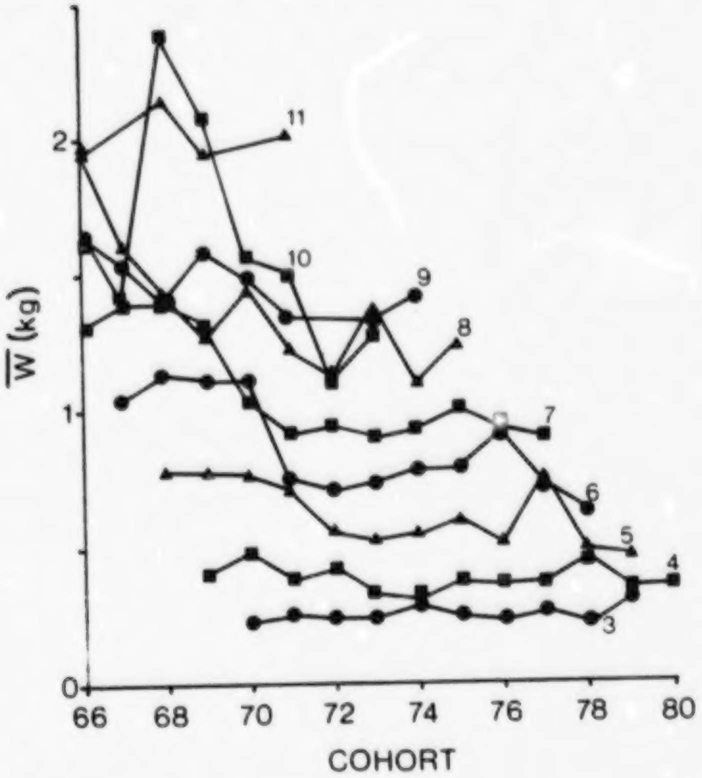


Fig. 53. Lack of compensatory responses in growth ($\bar{W}$ = mean individual body weight) of whitefish age groups in northern Lake Winnipeg.

DISCUSSION

Historical Development of the Lake Winnipeg Fish Stock Assessment and Management Programs

The development of Lake Winnipeg's fish stock assessment and management programs may be chronologically divided into three phases:

a. 1930 - 1970 Bajkov (1930, 1933) and Grant (1938) produced the first descriptions of Lake Winnipeg's fisheries. Later studies were limited to one species or short term (1-7 years) data sets (Hewson 1951, 1953, 1957, 1959a, 1959b, 1960; Kennedy 1954; Kooyman 1952, 1955; Rybicki 1961, 1962). This phase was characterized by a complete absence of a standardized stock assessment program that routinely documented the status of all commercially important species from all areas of the lake.

Commercial catches of north basin whitefish were sampled regularly from 1959 to 1969 (Davidoff *et al*. 1973).

During this period, management regulations developed independently since few biological inputs were available. During the 1940's, few regulatory areas existed and a large (4.25 inch) minimum mesh size gillnet was allowed for use by fishermen. A three inch mesh size gillnet, was first gazetted for Lake Winnipeg's south basin in 1942 (Beyette, 1980). From the 1950's until 1970, the creation of several new regulatory areas and the north-south gradient in minimum mesh sizes evolved primarily in responses to demands by commercial fishermen. The use of trap nets, first gazetted in 1960 (Beyette 1980), marked the beginning of the fishery's demise. The economic collapse in 1969 was followed by a two year moratorium caused by excessive amounts of mercury in walleyes and saugers. Substantial increases in total annual fishing effort were due to increases in numbers of new fishermen that were permitted access to the fishery, technological improvements and the relaxation of regulatory restraints. Daily gillnet yardage allowances increased, quotas increased and mesh sizes decreased.

b. 1970 - 1979

Commercial quotas on seasonal catches of walleyes, saugers and whitefish from various regulatory zones were reduced in 1972 in an attempt to allow recovery of stocks. The use of trap nets was prohibited. However the pre 1970 mesh size and daily net yardage allowances as well as the regulatory zone boundaries remained and quotas and numbers of new fishermen gradually increased (Tables 32-34).

Age, length and weight data were collected from commercial catches of north basin whitefish and channel and south basin walleyes and saugers. An annual experimental gillnetting program to provide data independent of commercial catches began in 1972 but collected only data from the north basin whitefish stock. Experimental gillnetting to provide data from the channel and south basin walleye and sauger stocks commenced in 1976. An annual trawling program to assess densities of juvenile walleyes and saugers in the channel and south basin commenced in 1976 but was not systematic in spatial and temporal terms (Kristofferson 1985).

c. 1979 - 1985

A standardized experimental gillnetting and commercial catch sampling program covering all major areas of Lake Winnipeg commenced in 1979. This marks the first time that walleye and sauger stocks from all three major areas were systematically sampled with experimental nets and the first time that commercial catches of walleyes and saugers from the north basin were sampled.

The first attempts to comprehensively describe growth and maturity regimes of commercial stocks in major areas of Lake Winnipeg and to relate stock responses to fishery effects were made in 1979. From 1979 to 1983, the annual stock assessment reports routinely described age-specific growth, maturity and mortality regimes determined by analyses of experimental gillnetting data, mesh-specific frequencies of mature fish and CUE and age frequencies and related body size estimates of commercially caught walleyes, saugers and whitefish. Annual species specific catch and effort data provided by Manitoba Fisheries Branch and the FFMC were documented.

In 1984, the responsibility for the annual Lake Winnipeg data analyses was transferred from the author to other staff members.

Management regulations continued to change primarily to meet increasing demands by Lake Winnipeg fishermen for larger fishing zones, more fishing zones, larger individual quotas and more seasons

(Tables 32-35).

This report presents the first attempt to comprehensively describe spatial and temporal changes in walleye and sauger cohort biomasses in relation to environmental and fishery changes. Analyses of cohort dynamics are crucial in elucidating compensatory responses of fish stocks to naturally or anthropogenically induced stressors. The annual assessments of growth, maturity and mortality (Lysack 1980-1984) were merely "point in time" cross sections of cohort regimes. This explains why annual rate estimates varied erratically from year to year.

Paralimnological Effects on Cohort Strength

The work of Brunskill (see "references") and other research scientists from the Canada Dept. of Fisheries and Oceans demonstrated that the hydrological regimes of Lake Winnipeg's incurrent rivers profoundly affect abiotic and biotic processes occurring in Lake Winnipeg. Incurrent rivers create warm thermal plumes in spring. Their nutrient loads directly affect primary productivity and their suspended sediment loads indirectly affect primary productivity by controlling light attenuation. Patalas (1981) related the spatial distribution and abundance of Lake Winnipeg's crustacean zooplankton to hydrological effects. Flannigan (1980) documented the relationship of benthic invertebrates to various physical and chemical processes controlled by hydrological regimes.

Various anthropogenic activities are modifying the hydrological regimes of Lake Winnipeg's incurrent rivers. On Lake Winnipeg's western shores, the physical characteristics of incurrent rivers are modified by channelization, removal of riparian zones and construction of various types of water control structures. Increasing urbanization and agricultural development are continually increasing the amounts of sediments and nutrients carried into Lake Winnipeg by rivers which drain vast watersheds. In the north west region of the lake, these effects have been ameliorated by the construction of a hydro electric dam at the mouth of the Saskatchewan River. The Cedar Lake reservoir behind this dam is acting as a settling basin for sediments and nutrients. The hydrological regimes of rivers draining Lake Winnipeg's eastern area are being modified by logging activities and the development of parks and roads. A hydro electric dam exists at the mouth of the Winnipeg River. Human activities are expanding in a northern direction along both eastern and western shores.

Vernal flow rates of incurrent rivers and vernal warming rates of Lake Winnipeg's water are strongly correlated to abundances of juvenile walleyes and saugers. These two environmental variables are simple indices of complex processes that ultimately influence the trophic dynamics of newly hatched fish. Flow rate is a simple indicator of nutrient loading which affects primary and secondary productivity which in turn affect the amount of food available to juvenile fish. Vernal warming rate is a simple indicator of trophic energy transfer rates which also affect the amount of food available to newly hatched fish.

The use of vernal flow rates and water warming rates to account for environmental effects on cohort strengths of walleyes and saugers may be of considered analogous to the use of morphoedaphic indices to predict fish yields, in "true" lakes. In this regard, Lake Winnipeg is a riverine system because its water retention time is relatively short and its biophysical and biochemical regimes are controlled by incurrent rivers. Welcomme (1979) presented several cases which document the intimate relationship of hydrological regimes and catches and dynamics of fish stocks in large rivers.

From a geological perspective, lakes are temporary phenomena. Sediments carried by tributaries will eventually fill lake basins. This process is accelerated in watersheds where agricultural and logging activities are increasing soil erosion rates. As lakes become shallower, the paralimnological effects of their tributaries become more pronounced. Thus the various morphoedaphic indices of fish yield become less static and vary as a function of tributary flow regimes. Future work on yield prediction models for such systems should incorporate the dynamic effect of tributaries on morphoedaphic indices.

Potential fish yield estimates (kg ha^{-1} year $^{-1}$) for Lake Winnipeg from various empirical models are 1.27 - 2.06 (yield as a function of chlorophyll a, Oglesby 1977, Oglesby et al. 1986), 2.0 (yield as a function of surface area, Youngs and Heimbuch 1982) and 2.93 (yield as a function of macrobenthic biomass, Matuszek 1978). The long term mean observed commercial yield of the Lake Winnipeg fishery ws 2.57 kg ha^{-1} $year^{-1}$ (from Table 31). The maximum yield predicted as a function of recent fishing effort was 2.22 kg ha^{-1} $year^{-1}$ (Fig. 50).

The term "sustained yield", has been avoided throughout this report since commercial catches have never been "sustained" or stable even at low levels of fishing effort.

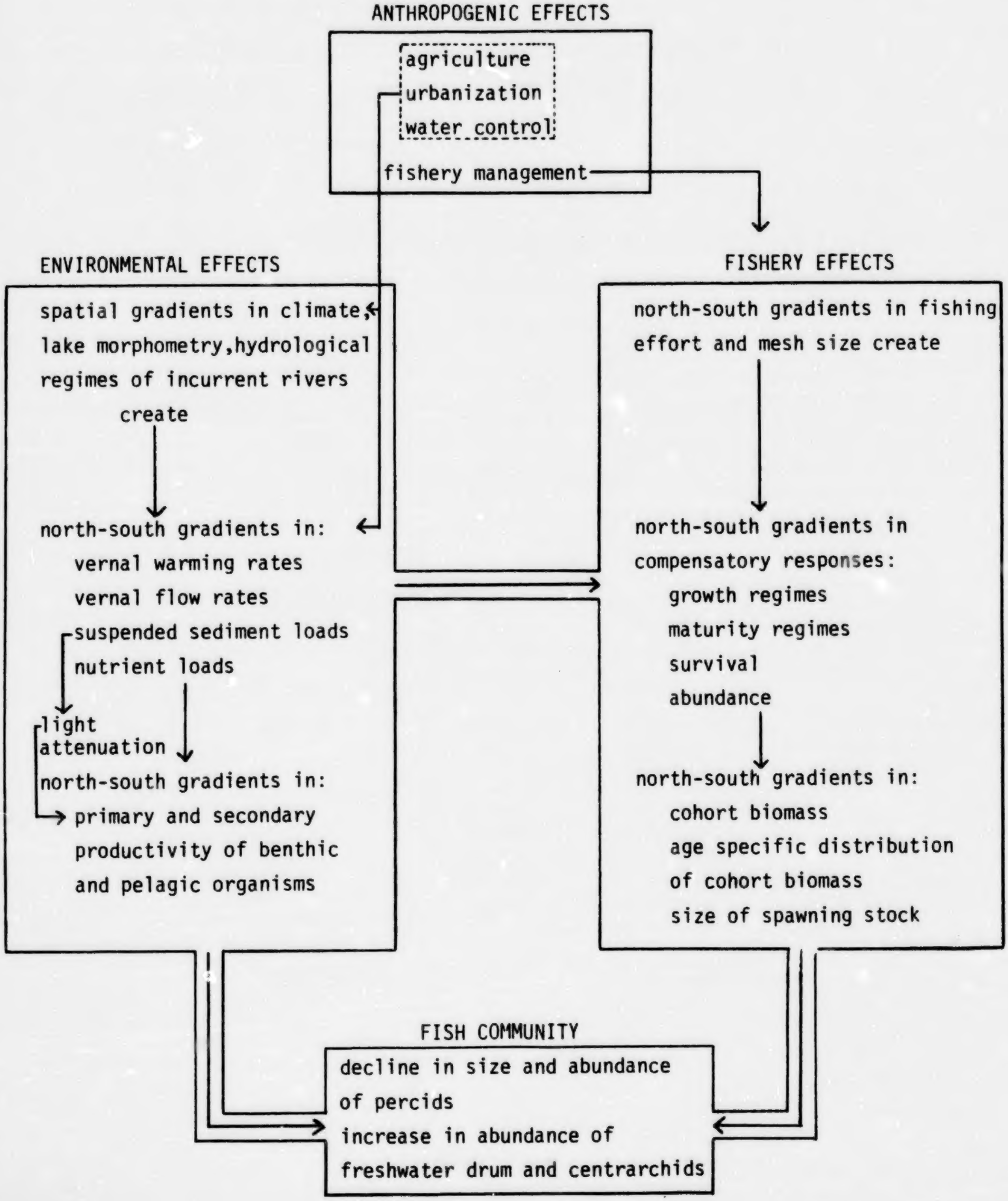
Fishery Effects on Cohort Strengths

The use of vernal flow rates and warming rates in explaining annual variations in cohort strengths of walleyes and saugers accounts for the effect of the environment. However, cohort biomass is also a function of spawning stock size which is directly controlled by fishing effort and gear characteristics. Spatial differences between north basin and south basin walleye and sauger spawning stock size (Table 28) reflect spatial differences in fishing effort, and mesh sizes of commercial gillnets. Within the south basin fishery, temporal changes in fishing effort (Table 37) are generally inversely proportional to the spawning female biomass of walleyes and saugers (see "variable recruitment", Table 28). This implies that relatively low fishing effort during 1974-75 (Table 40) increased escapement of female spawners whose eggs hatched in optimal environmental conditions (Table 21) resulting in the development of large cohort biomasses (Figs. 43,44). The coincidence of relatively large spawning stocks of south basin walleyes and saugers and optimal environmental conditions in 1979 should result in relatively high commercial yields during 1985-86. Commercial yields of south basin walleyes and saugers will probably decrease during 1987-89 since relatively weak cohorts were developed during 1980-82. Walleye yields should increase at the end of the decade since the 1983 spawning stock size was relatively large and favourable environmental conditions existed.

A crude analysis of recent catch and effort data (Fig. 50) indicates that the optimum yield of all commercially exploited species was 2.22 kg ha^{-1} $year^{-1}$. The effort required to produce this yield was approximately 31,600 deliveries. The quota entitlement system instituted in 1985 guarantees Lake Winnipeg's commercial fishermen an annual, whole lake quota of 6,800,000 kg of walleyes, saugers and whitefish. This is equivalent to 2.86 kg ha^{-1} $year^{-1}$ of only quota species. If this quota amount of walleyes, saugers and whitefish continues to be annually removed, another economic collapse, similar to the 1969 collapse, is eminent.

Recent, undocumented evidence indicates that the stability of Lake Winnipeg's fish community is eroding. The dominance of freshwater drum (see Fig. 14, Lysack 1981), white bass and black crappies is slowly increasing as the large and intermediate sized percids (walleyes and saugers) decrease and the small percids (yellow perch) increase.

A conception of the interrelationships of processes controlling percid stocks and possible fish community response in Lake Winnipeg may be depicted as follows:


ANTHROPOGENIC EFFECTS
agriculture
urbanization
water control
fishery management
ENVIRONMENTAL EFFECTS
spatial gradients in climate,
lake morphometry, hydrological
regimes of incurrent rivers
create
north-south gradients in:
vernal warming rates
vernal flow rates
suspended sediment loads
nutrient loads
light
attenuation
north-south gradients in:
primary and secondary
productivity of benthic
and pelagic organisms
FISHERY EFFECTS
north-south gradients in fishing
effort and mesh size create
north-south gradients in
compensatory responses:
growth regimes
maturity regimes
survival
abundance
north-south gradients in:
cohort biomass
age specific distribution
of cohort biomass
size of spawning stock
FISH COMMUNITY
decline in size and abundance
of percids
increase in abundance of
freshwater drum and centrarchids

Required Refinements and Additional Work

To quantify the model predicting abundance of juvenile walleyes and saugers as a function of escaped female spawning biomass and warming and flow rates, daily water temperatures measured during May and June are required. Continuation of an annual, systematic experimental gillnetting and commercial catch sampling program is essential to provide estimates of various parameters relating to the growth and decay of cohort biomass. Year-to-year variations in estimates of age-specific sex ratios and frequencies of mature fish experimentally netted in the north bsin have confounded the interpolation of cohort related maturity regimes. Estimates of escaped female spawning biomass should be refined by accounting for age specific sex ratios.

Spatial and temporal changes in species proportions comprising Lake Winnipeg's fish community have been largely undocumented. These should be recorded in terms of numbers and individual weights as estimated by experimental gillnetting. Spatial and temporal changes in abundance and biomass of small forage fish have never been systematically monitored in Lake Winnipeg. These data are crucial to an analysis of fish community stability.

Refined estimates of commercial catch and effort data are required. Presently, we do not know the amounts of fish culled from catches before marketing. The components of a "delivery" as reported by the FFMC should be quantified. The round weight-dressed weight discrepancy is currently circumvented by the use of extremely crude conversion factors. These factors should be refined by correlating round weights and dressed weights of individual fish.

The error structure associated with estimates of growth and maturity parameters should be described in order to choose appropriate transformations. Growth and maturity regimes of individual cohorts should be quantified when data on more complete cohorts are collected.

Due to various methodological difficulties, abundance data of juvenile whitefish, walleyes and saugers in Lake Winnipeg's north basin are not available. New methodologies relating to this problem should be developed.

The present methodology of ageing fish collected during the annual stock assessment program should remain unaltered.

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APPENDIX A

Multiple regressions of walleye and sauger CUE values as functions of warming rates and flow rates of Lake Winnipeg's incurrent rivers

```
           SIMPLE CORRELATIONS   South Basin

           WALLEYE   SAUGER    WARM      RED       WPG       MAN       BRHD
WALLEYE   1.0000
SAUGER    0.2437    1.0000
WARM      0.1527    0.7161    1.0000
RED       0.2426    0.9829    0.6905    1.0000
WPG       0.4616    0.8703    0.5562    0.8954    1.0000
MAN       0.5021    0.9258    0.6066    0.9515    0.9657    1.0000
BRHD      0.6185    0.9059    0.6140    0.8875    0.9120    0.9584    1.0000

 DEGREES OF FREEDOM            5
 CASES INCLUDED                7        MISSING CASES    0


           SIMPLE CORRELATIONS   South Channel

           WALLEYE   SAUGER    WARM      FISHER    BERENS    MAN       PIGEON
WALLEYE   1.0000
SAUGER    0.5418    1.0000
WARM      0.2068    0.0660    1.0000
FISHER    0.2007    0.1351    0.7130    1.0000
BERENS    0.2737   -0.0246    0.2863    0.8232    1.0000
MAN       0.5601    0.2175    0.6066    0.9001    0.8828    1.0000
PIGEON    0.1923   -0.0469    0.2489    0.8051    0.9938    0.8423    1.0000

 DEGREES OF FREEDOM            5
 CASES INCLUDED                7        MISSING CASES    0


           SIMPLE CORRELATIONS   North & South Channel

           WALLEYE   SAUGER    WARM      FISHER    BERENS    MAN       PIGEON
WALLEYE   1.0000
SAUGER    0.7946    1.0000
WARM      0.4760    0.0335    1.0000
FISHER    0.5250   -0.0637    0.7130    1.0000
BERENS    0.4932    0.0070    0.2863    0.8232    1.0000
MAN       0.7935    0.3007    0.6066    0.9001    0.8828    1.0000
PIGEON    0.4155   -0.0620    0.2489    0.8051    0.9938    0.8423    1.0000

 DEGREES OF FREEDOM            5
 CASES INCLUDED                7        MISSING CASES    0
```

SOUTH BASIN WALLEYES

```
UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR WALLEYE

PREDICTOR
VARIABLES     COEFFICIENT    STD ERROR    STUDENT'S T      P
---------     -----------    ---------    -----------    ------
CONSTANT       -1.705        1.160           -1.47       0.3804
WARM            10.82        4.782            2.26       0.2649
RED            -1.066E-02    8.797E-04      -12.12       0.0524
WPG            -6.648E-03    1.354E-03       -4.91       0.1279
MAN             6.358E-01    8.495E-02        7.48       0.0846
BRHD            1.798E-01    7.014E-02        2.56       0.2368

CASES INCLUDED            7        MISSING CASES    0
DEGREES OF FREEDOM        1
OVERALL F             66.08        P VALUE      0.0939
ADJUSTED R SQUARED   0.9819
R SQUARED            0.9970
MEAN SQUARED ERROR    1.446E-01


                    STEPWISE ANALYSIS OF VARIANCE OF WALLEYE

           INDIVIDUAL    CUM   CUMULATIVE   CUMULATIVE   ADJUSTED    MALLOW'S
SOURCE         SS         DF       SS           MS       R-SQUARED      CP      P
--------   ----------   ----   ----------   ----------   ---------   --------  ---
CONSTANT   35.618
WARM       1.1182          1   1.1182       1.1182       -0.1720      320.7     2
RED        1.7235          2   2.8417       1.4209       -0.4111      310.7     3
WPG        14.774          3   17.616       5.8720       -0.2650      210.6     4
MAN        29.222          4   46.837       11.709        0.9315       10.6     5
BRHD       0.9502          5   47.788       9.5575        0.9819        6.0     6
RESIDUAL   1.4464E-01      6   47.932       7.9887

CASES INCLUDED            7        MISSING CASES    0
DEGREES OF FREEDOM        1
OVERALL F             66.08        P VALUE      0.0939
ADJUSTED R SQUARED   0.9819
R SQUARED            0.9970
MEAN SQUARED ERROR    1.446E-01
```

SOUTH BASIN SAUGERS

```
UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR SAUGER

PREDICTOR
VARIABLES     COEFFICIENT    STD ERROR    STUDENT'S T      P
----------    -----------    ---------    -----------    ------
CONSTANT       2.723E-01     1.066             0.26      0.8407
WARM          -1.095         4.394            -0.25      0.8445
RED            5.067E-03     8.083E-04         6.27      0.1007
WPG            1.431E-03     1.244E-03         1.15      0.4557
MAN           -2.147E-01     7.805E-02        -2.75      0.2219
BRHD           2.170E-01     6.444E-02         3.37      0.1838

CASES INCLUDED              7        MISSING CASES     0
DEGREES OF FREEDOM          1
OVERALL F               80.15        P VALUE      0.0853
ADJUSTED R SQUARED  0.9851
R SQUARED           0.9975
MEAN SQUARED ERROR   1.221E-01


                     STEPWISE ANALYSIS OF VARIANCE OF SAUGER

          INDIVIDUAL   CUM    CUMULATIVE    CUMULATIVE    ADJUSTED     MALLOW'S
SOURCE        SS        DF       SS             MS        R-SQUARED       CP       P
--------  ----------   ----   ----------    ----------    ---------    --------   ---
CONSTANT  20.678
WARM      25.160         1    25.160        25.160         0.4154       192.7      2
RED       22.373         2    47.533        23.766         0.9533        11.5      3
WPG       7.3258E-03     3    47.540        15.847         0.9380        13.5      4
MAN       1.4298E-02     4    47.554        11.889         0.9079        15.3      5
BRHD      1.3848         5    48.939        9.7878         0.9851         6.0      6
RESIDUAL  1.2212E-01     6    49.061        8.1769

CASES INCLUDED              7        MISSING CASES     0
DEGREES OF FREEDOM          1
OVERALL F               80.15        P VALUE      0.0853
ADJUSTED R SQUARED  0.9851
R SQUARED           0.9975
MEAN SQUARED ERROR   1.221E-01
```

SOUTH CHANNEL WALLEYES

```
UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR WALLEYE

PREDICTOR
VARIABLES     COEFFICIENT    STD ERROR     STUDENT'S T       P
---------     -----------    ---------     -----------     ------
CONSTANT        21.31        2.002E-01       106.48        0.0060
WARM           -74.55        7.634E-01       -97.65        0.0065
FISHER         -6.748E-01    7.623E-03       -88.52        0.0072
BERENS         -1.835E-01    9.899E-03       -18.53        0.0343
MAN             1.059        4.063E-03       260.76        0.0024
PIGEON         -1.154E-01    4.548E-03       -25.38        0.0251

CASES INCLUDED              7       MISSING CASES    0
DEGREES OF FREEDOM          1
OVERALL F             3.831E+04    P VALUE       0.0039
ADJUSTED R SQUARED   1.0000
R SQUARED            1.0000
MEAN SQUARED ERROR    1.104E-03


                       STEPWISE ANALYSIS OF VARIANCE OF WALLEYE

          INDIVIDUAL    CUM    CUMULATIVE     CUMULATIVE   ADJUSTED    MALLOW'S
SOURCE        SS        DF        SS              MS       R-SQUARED      CP       P
--------  ----------   ----   ----------     ----------   ---------   --------   ---
CONSTANT  118.84
WARM      9.0458          1   9.0458         9.0458        -0.1487   183370.2     2
FISHER    1.2196          2   10.265         5.1327        -0.4272   182267.5     3
BERENS    33.205          3   43.470         14.490        -0.5889   152192.2     4
MAN       167.30          4   210.77         52.693         0.9899      648.3     5
PIGEON    7.1130E-01      5   211.49         42.297         1.0000        6.0     6
RESIDUAL  1.1040E-03      6   211.49         35.248

CASES INCLUDED              7       MISSING CASES    0
DEGREES OF FREEDOM          1
OVERALL F             3.831E+04    P VALUE       0.0039
ADJUSTED R SQUARED   1.0000
R SQUARED            1.0000
MEAN SQUARED ERROR    1.104E-03
```

SOUTH CHANNEL SAUGERS

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UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR SAUGER

PREDICTOR
VARIABLES     COEFFICIENT    STD ERROR     STUDENT'S T      P
---------     -----------    ---------     -----------    ------
CONSTANT        20.28        3.923               5.17     0.1217
WARM           -70.68        14.96              -4.72     0.1328
FISHER          4.175E-01    1.494E-01           2.79     0.2188
BERENS         -6.717E-01    1.940E-01          -3.46     0.1790
MAN             3.922E-01    7.962E-02           4.93     0.1275
PIGEON          2.032E-01    8.913E-02           2.28     0.2631

CASES INCLUDED              7       MISSING CASES    0
DEGREES OF FREEDOM          1
OVERALL F               6.707       P VALUE      0.2873
ADJUSTED R SQUARED     0.8263
R SQUARED              0.9710
MEAN SQUARED ERROR    4.240E-01
```

```
                                 STEPWISE ANALYSIS OF VARIANCE OF SAUGER

          INDIVIDUAL    CUM    CUMULATIVE    CUMULATIVE   ADJUSTED     MALLOW'S
SOURCE        SS         DF        SS            MS       R-SQUARED       CP       P
--------  ----------   ----   ----------    ----------   ---------    --------   ---
CONSTANT  19.492
WARM      6.3792E-02      1   6.3792E-02    6.3792E-02   -0.1948         31.4      2
FISHER    2.3066E-01      2   2.9445E-01    1.4723E-01   -0.4698         32.8      3
BERENS    2.5179          3   2.8123        9.3744E-01   -0.6159         28.9      4
MAN       9.2023          4   12.015        3.0036        0.4614          9.2      5
PIGEON    2.2048          5   14.219        2.8439        0.8263          6.0      6
RESIDUAL  4.2404E-01      6   14.643        2.4406

CASES INCLUDED              7       MISSING CASES    0
DEGREES OF FREEDOM          1
OVERALL F               6.707       P VALUE      0.2873
ADJUSTED R SQUARED     0.8263
R SQUARED              0.9710
MEAN SQUARED ERROR    4.240E-01
```

NORTH AND SOUTH (POOLED) CHANNEL WALLEYES

```
UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR WALLEYE

PREDICTOR
VARIABLES     COEFFICIENT    STD ERROR     STUDENT'S T       P
---------     -----------    ---------     -----------    ------
CONSTANT        9.762        1.762             5.54       0.1137
WARM          -33.02         6.720            -4.91       0.1278
FISHER        -1.778E-01     6.710E-02        -2.65       0.2297
BERENS        -1.370E-01     8.713E-02        -1.57       0.3607
MAN            5.494E-01     3.576E-02        15.36       0.0414
PIGEON        -4.010E-02     4.003E-02        -1.00       0.4994

CASES INCLUDED              7       MISSING CASES     0
DEGREES OF FREEDOM          1
OVERALL F               170.3       P VALUE       0.0586
ADJUSTED R SQUARED     0.9930
R SQUARED              0.9988
MEAN SQUARED ERROR     8.554E-02
```

```
                        STEPWISE ANALYSIS OF VARIANCE OF WALLEYE

           INDIVIDUAL   CUM   CUMULATIVE   CUMULATIVE   ADJUSTED    MALLOW'S
SOURCE         SS        DF       SS           MS       R-SQUARED      CP       P
--------   ----------   ----  ----------   ----------   ---------   --------   ---
CONSTANT   55.387
WARM       16.520         1   16.520       16.520        0.0719      656.4      2
FISHER     5.1113         2   21.632       10.816       -0.0550      598.6      3
BERENS     7.9926         3   29.624       9.8747       -0.1875      507.2      4
MAN        43.127         4   72.751       18.188        0.9929        5.0      5
PIGEON     8.5841E-02     5   72.837       14.567        0.9930        6.0      6
RESIDUAL   8.5539E-02     6   72.922       12.154

CASES INCLUDED              7       MISSING CASES     0
DEGREES OF FREEDOM          1
OVERALL F               170.3       P VALUE       0.0586
ADJUSTED R SQUARED     0.9930
R SQUARED              0.9988
MEAN SQUARED ERROR     8.554E-02
```

NORTH AND SOUTH (POOLED) CHANNEL SAUGERS

```
UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR SAUGER

PREDICTOR
VARIABLES     COEFFICIENT    STD ERROR     STUDENT'S T       P
---------     -----------    ---------     -----------     ------
CONSTANT        18.49        5.266               3.51      0.1766
WARM           -62.98        20.08              -3.14      0.1965
FISHER        -3.704E-01     2.006E-01          -1.85      0.3159
BERENS        -5.010E-01     2.604E-01          -1.92      0.3052
MAN            7.384E-01     1.069E-01           6.91      0.0915
PIGEON         9.086E-02     1.196E-01           0.76      0.5865

CASES INCLUDED            7        MISSING CASES     0
DEGREES OF FREEDOM        1
OVERALL F             17.82        P VALUE      0.1794
ADJUSTED R SQUARED   0.9334
R SQUARED            0.9889
MEAN SQUARED ERROR    7.641E-01
```

```
                           STEPWISE ANALYSIS OF VARIANCE OF SAUGER

          INDIVIDUAL   CUM   CUMULATIVE    CUMULATIVE   ADJUSTED    MALLOW'S
SOURCE        SS        DF       SS            MS       R-SQUARED      CP      P
--------  ----------  ----  ----------    ----------  ---------   --------   ---
CONSTANT  44.599
WARM      7.7116E-02     1  7.7116E-02    7.7116E-02  -0.1987        87.0      2
FISHER    1.0737         2  1.1508        5.7540E-01  -0.4749        87.6      3
BERENS    5.7685         3  6.9193        2.3064      -0.7990        82.1      4
MAN       60.740         4  67.660        16.915       0.9475         4.6      5
PIGEON    4.4070E-01     5  68.100        13.620       0.9334         6.0      6
RESIDUAL  7.6411E-01     6  68.864        11.477

CASES INCLUDED            7        MISSING CASES     0
DEGREES OF FREEDOM        1
OVERALL F             17.82        P VALUE      0.1794
ADJUSTED R SQUARED   0.9334
R SQUARED            0.9889
MEAN SQUARED ERROR    7.641E-01
```

APPENDIX B

QUOTA SPECIES VALUES

Table B1. Quota species values ($\$\ kg^{-1}$) to fishermen.

Species	Type		1976		1977		1978		1979		1980		1981		1982		1983	
			summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
Whitefish	Export	Jumbo	1.30	1.52	1.38	1.59	1.55	2.00	1.28	1.50	1.21	1.54		1.16	1.03	1.32	0.86	1.32
		Large	1.08	1.30	1.15	1.38	1.33	1.77	1.06	1.28	1.06	1.32		0.99	0.92	1.21	0.84	1.21
		Medium	0.86	1.08	0.93	1.15	1.11	1.77	0.84	1.06	0.88	1.10		0.83	0.81	1.10	0.81	1.10
		Small	0.60	0.82	0.67	0.67	0.85	1.33	0.62	0.73	0.66	0.88		0.83	0.59	0.88	0.55	0.88
	Continental	Jumbo	0.86	0.97	0.86	0.86	1.01	1.23	0.90	0.94	0.79	0.95		0.71	0.66	0.77	0.62	0.77
		Large	0.64	0.75	0.64	0.64	0.79	1.12	0.68	0.79	0.68	0.82		0.61	0.66	0.77	0.62	0.77
		Medium	0.64	0.75	0.64	0.64	0.79	1.12	0.68	0.79	0.68	0.82		0.61	0.66	0.77	0.62	0.77
		Small	0.42	0.53	0.42	0.42	0.57	0.79	0.46	0.57	0.57	0.68		0.51	0.66	0.77	0.55	0.66
	Smoker	Large							1.17	1.39	1.17	1.43			0.92		0.92	
		Medium	1.12	1.12	1.10	1.10	1.36	1.36	1.17	1.17	1.17	1.21			0.92		0.92	
		small							0.84	0.84								
	Cutter		0.35	0.35	0.22	0.22	0.41	0.41	0.44	0.55	0.44	0.55		2.15		0.60	0.48	0.60
Walleye	Round	Large	1.51	1.87	1.57	1.90	1.59	2.36	1.54	1.96	1.54	1.98		2.15	1.54	1.54	1.23	1.54
		Medium	1.51	1.87	1.57	1.90	1.59	2.36	1.43	1.65	1.54	1.98		1.65	1.54	1.54	1.34	1.76
		Small	1.51	1.87	1.57	1.57	1.59	1.76	1.15	1.15	1.26	1.54			1.54	1.43	1.23	1.54
	Dressed	Large	1.78	2.09	1.85	1.85	1.88	2.11	1.83	1.83					1.80	1.81	1.43	1.81
		Medium	1.78	2.09	1.85	1.85	1.88	2.11	1.72	1.72					1.80	1.81	1.56	2.07
		Small	1.78	2.09	1.85	1.85	1.88	1.88	1.37	1.37					1.67	1.68	1.43	1.81
	Headless Dressed	Large	2.03	2.26	2.15	2.15	2.19	2.63	2.09	2.09	2.16	2.31			2.20	2.20	1.78	
		Medium	2.03	2.26	2.15	2.15	2.19	2.63	1.98	1.98	2.16	2.31			2.20	2.20	1.94	
		Small	2.03	2.26	2.15	2.15	2.19	2.19	1.76	1.76	1.76	1.87			2.09	2.09	1.78	
Sauger	Round	Large	1.32		0.97	0.97	0.77	1.32	0.79	1.01	1.10	1.43		1.49	1.43	1.43	1.23	1.54
		Medium	1.32		0.97	0.97	0.77	0.99	0.79	0.90	1.10	1.32		1.32	1.43	1.43	1.21	1.54
		Small				0.49	0.40											
	Headless Dressed	Large	1.82		1.32	1.32	1.03	1.25	1.10	1.10	1.54	1.65						
		Medium	1.82		1.32	1.32	1.03	1.25	1.10	1.10	1.54	1.65						
	Headless	Large													2.09	2.09	1.78	2.20
		Medium													2.09	2.09	1.76	2.20
	Dressed	Large														1.68	1.43	1.81
		Medium														1.68	1.41	1.81

APPENDIX C

MODELS PREDICTING ABUNDANCES OF YOY WALLEYES AND SAUGERS AS FUNCTIONS OF WATER WARMING RATES, FLOW RATES OF INCURRENT RIVERS AND BIOMASSES OF MATURE FEMALE WALLEYES AND SAUGERS ESCAPING LAKE WINNIPEG'S COMMERCIAL FISHERIES

The recent discovery of the 1983 surface water temperature data permitted quantification of the predictive models for walleyes and saugers. The following analyses use these codes:

SA- observed annual mean number of yoy saugers per trawl

WA- observed annual mean number of yoy walleyes per trawl

BIO- biomass of mature females annualy escaping the commercial fishery

RED- mean May flow rate of the Red River (m^3 sec^{-1}) station 050J010

WPG- mean May flow rate of the Winnipeg River (m^3 sec^{-1}) station 05PF063

MAN- mean May flow rate of the Manigotagan River (m^3 sec^{-1}) station 05RA001

BRK- mean May flow rate of the Brokenhead River (m^3 sec^{-1}) station 05SA004

WARM- vernal warming rate of Lake Winnipeg's water (^{o}C day^{-1}) determined by LSR from surface water temperatures recorded daily at Gimli from spring breakup to June 30.

MEANFLOW- mean May flow rate of the Red, Winnipeg, Manigotagan and Brokenhead Rivers.

PREDICT- predicted annual mean number of yoy fish per trawl

RESID- observed-predicted residual

Each of the five data sets were determined annualy from 1979 to 1983.

Abundance (mean no. $trawl^{-1}$) of each species is predicted as a function of BIO, WARM and MEANFLOW.

```
UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR SA

PREDICTOR
VARIABLES     COEFFICIENT     STD ERROR      STUDENT'S T        P
---------     -----------     ---------      -----------     ------
CONSTANT        -2.785        1.868              -1.49       0.3762
BIOSA            1.491E-03    1.076E-03           1.39       0.3979
WARM             1.425E-01    8.437               0.02       0.9892
MEANFLOW         9.553E-03    1.537E-03           6.21       0.1016

CASES INCLUDED              5         MISSING CASES     0
DEGREES OF FREEDOM          1
OVERALL F               21.94         P VALUE      0.1586
ADJUSTED R SQUARED     0.9401
R SQUARED              0.9850
MEAN SQUARED ERROR       7.021E-01
```

```
                         STEPWISE ANALYSIS OF VARIANCE OF SA

          INDIVIDUAL   CUM   CUMULATIVE   CUMULATIVE   ADJUSTED    MALLOW'S
SOURCE       SS         DF       SS           MS       R-SQUARED      CP       P
--------  ----------   ----  ----------   ----------   ---------   --------   ---
CONSTANT  19.075
BIOSA     1.0120         1    1.0120       1.0120       -0.3046      64.4       2
WARM      18.095         2    19.107       9.5535       -0.1854      40.6       3
MEANFLOW  27.104         3    46.211       15.404        0.9401       4.0       4
RESIDUAL  7.0209E-01     4    46.913       11.728

CASES INCLUDED              5         MISSING CASES     0
DEGREES OF FREEDOM          1
OVERALL F               21.94         P VALUE      0.1586
ADJUSTED R SQUARED     0.9401
R SQUARED              0.9850
MEAN SQUARED ERROR       7.021E-01
```

```
                                              NON-
VARIABLE        MEAN        S.D.      MISSING  MISSING     MINIMUM     MAXIMUM
---------    ----------  ---------    -------  -------   ----------  ----------
SA             1.953      3.425           5         0     1.034E-01   8.063
WARM           2.422E-01  6.445E-02       5         0     1.630E-01   3.190E-01
RED            637.5      891.3           5         0     59.30       2.200E+03
WPG            791.6      504.0           5         0     264.0       1.620E+03
MAN            16.69      18.49           5         0     3.070       48.50
BRK            6.714      9.494           5         0     2.520E-01   23.40
BIOSA          828.5      395.4           5         0     339.7       1.301E+03
MEANFLOW       363.1      351.4           5         0     81.66       973.0
PREDICTSA      1.953      3.399           5         0    -3.699E-02   7.998
RESIDSA       -8.095E-12  4.190E-01       5         0    -6.922E-01   4.148E-01
```

```
          SA           WARM         RED          WPG          MAN          BRK
  1   8.0632       3.1900E-01   2200.0       1620.0       48.500       23.400
  2   1.0340E-01   2.3900E-01   99.100       735.00       8.2300       1.4100
  3   3.7780E-01   1.9800E-01   59.300       264.00       3.0700       2.5200E-01
  4   8.0150E-01   1.6300E-01   495.00       766.00       16.900       3.9800
  5   4.2000E-01   2.9200E-01   334.00       573.00       6.7500       4.5300
        BIOSA        MEANFLOW     PREDICTSA    RESIDSA
  1   967.87       972.97       7.9975       6.5682E-02
  2   1027.5       210.93       7.9559E-01  -6.9219E-01
  3   1301.3       81.655      -3.6989E-02   4.1479E-01
  4   339.68       320.47       8.0561E-01  -4.1133E-03
  5   506.35       229.57       2.0417E-01   2.1583E-01
```

```
                    RANKITS VS RESIDSA
  RANKITS
   1.2 +                                     +
       :
       :
       :
       :                               +
   0.4 +
       :
       :                          +
       :
       :
  -0.4 +
       :                       +
       :
       :
       :
  -1.2 ++
       -+---------+---------+---------+---------+-
      -7.0      -4.0      -1.0       2.0       5.0
                         RESIDSA X 10E-1
         APPROX. WILK-SHAPIRO 0.8693   5 CASES PLOTTED
```

```
UNWEIGHTED LEAST SQUARES LINEAR REGRESSION FOR WA

PREDICTOR
VARIABLES     COEFFICIENT     STD ERROR     STUDENT'S T        P
----------    -----------     ---------     -----------     ------
CONSTANT         1.769        1.758E-01        10.06        0.0631
BIOWA            2.798E-03    1.091E-04        25.65        0.0248
WARM            -8.346        9.473E-01        -8.81        0.0720
MEANFLOW         1.667E-03    1.030E-04        16.18        0.0393

CASES INCLUDED               5        MISSING CASES     0
DEGREES OF FREEDOM           1
OVERALL F                645.5        P VALUE      0.0295
ADJUSTED R SQUARED      0.9979
R SQUARED               0.9995
MEAN SQUARED ERROR   2.763E-03


                     STEPWISE ANALYSIS OF VARIANCE OF WA

             INDIVIDUAL    CUM    CUMULATIVE    CUMULATIVE    ADJUSTED    MALLOW'S
SOURCE           SS         DF        SS            MS        R-SQUARED      CP       P
--------     ----------    ----   ----------    ----------    ---------   --------   ---
CONSTANT     9.8845
BIOWA        4.6187          1    4.6187        4.6187         0.8170      264.9      2
WARM         8.3298E-03      2    4.6270        2.3135         0.7286      263.9      3
MEANFLOW     7.2365E-01      3    5.3507        1.7836         0.9979        4.0      4
RESIDUAL     2.7631E-03      4    5.3534        1.3384

CASES INCLUDED               5        MISSING CASES     0
DEGREES OF FREEDOM           1
OVERALL F                645.5        P VALUE      0.0295
ADJUSTED R SQUARED      0.9979
R SQUARED               0.9995
MEAN SQUARED ERROR   2.763E-03
```

```
                       DESCRIPTIVE STATISTICS
                                        NON-
VARIABLE      MEAN         S.D.       MISSING  MISSING    MINIMUM      MAXIMUM
---------  ----------  ----------  -------  -------  ----------  ----------
WA         1.406       1.157            5        0    3.185E-01   2.700
WARM       2.422E-01   6.445E-02        5        0    1.630E-01   3.190E-01
RED        637.5       891.3            5        0    59.30       2.200E+03
WPG        791.6       504.0            5        0    264.0       1.620E+03
MAN        16.69       18.49            5        0    3.070       48.50
BRK        6.714       9.494            5        0    2.520E-01   23.40
BIOWA      376.4       469.0            5        0    17.79       1.065E+03
MEANFLOW   363.1       351.4            5        0    81.66       973.0
PREDICTWA  1.406       1.157            5        0    3.581E-01   2.696
RESIDWA    7.913E-12   2.628E-02        5        0   -3.958E-02   2.971E-02
```

```
          WA           WARM         RED          WPG          MAN          BRK
   1    2.5789       3.1900E-01   2200.0       1620.0       48.500       23.400
   2    4.2530E-01   2.3900E-01   99.100       735.00       8.2300       1.4100
   3    3.1850E-01   1.9800E-01   59.300       264.00       3.0700       2.5200E-01
   4    1.0074       1.6300E-01   495.00       766.00       16.900       3.9800
   5    2.7000       2.9200E-01   334.00       573.00       6.7500       4.5300
          BIOWA        MEANFLOW     PREDICTWA    RESIDWA
   1    664.59       972.97       2.5878      -8.9346E-03
   2    96.340       210.93       3.9559E-01   2.9711E-02
   3    37.640       81.655       3.5808E-01  -3.9576E-02
   4    17.790       320.47       0.9926       1.4761E-02
   5    1065.5       229.57       2.6960       4.0380E-03
```

```
                       RANKITS VS RESIDWA
     RANKITS
      1.2 +                                   +
          :
          :
          :
          :                           +
      0.4 +
          :
          :                      +
          :
          :
     -0.4 +
          :                +
          :
          :
          :
     -1.2 ++
         -+---------+---------+---------+---------+-
         -4.0      -2.0       0.0       2.0       4.0
                            RESIDWA X 10E-2
            APPROX. WILK-SHAPIRO 0.9653   5 CASES PLOTTED
```

```
           SIMPLE CORRELATIONS

           WA        SA        WARM      RED       WPG       MAN       BRK
WA        1.0000
SA        0.5786    1.0000
WARM      0.7957    0.6339    1.0000
RED       0.6433    0.9896    0.6243    1.0000
WPG       0.5695    0.9214    0.6023    0.9459    1.0000
MAN       0.5548    0.9730    0.5371    0.9877    0.9705    1.0000
BRK       0.6843    0.9876    0.6912    0.9960    0.9445    0.9751    1.0000
BIOWA     0.9288    0.3376    0.8331    0.3821    0.3087    0.2660    0.4469
BIOSA    -0.4197    0.1469    0.1162    0.0033   -0.0782   -0.0202    0.0170
MEANFLOW  0.6241    0.9774    0.6236    0.9930    0.9775    0.9941    0.9899
PREDICTSA 0.5457    0.9925    0.6387    0.9830    0.9535    0.9797    0.9824
RESIDSA   0.3021    0.1223   -0.0000    0.1142   -0.2040    0.0048    0.1022
PREDICTWA 0.9997    0.5832    0.7959    0.6460    0.5651    0.5553    0.6867
RESIDWA   0.0227   -0.1955    0.0000   -0.1110    0.1988   -0.0173   -0.1003

           BIOWA     BIOSA     MEANFLOW  PREDICTSA RESIDSA   PREDICTWA RESIDWA
BIOWA     1.0000
BIOSA    -0.2999    1.0000
MEANFLOW  0.3595   -0.0261    1.0000
PREDICTSA 0.3053    0.1480    0.9848    1.0000
RESIDSA   0.2831   -0.0000    0.0000    0.0000    1.0000
PREDICTWA 0.9291   -0.4075    0.6242    0.5480    0.3212    1.0000
RESIDWA   0.0000   -0.5428    0.0000   -0.0941   -0.8346    0.0000    1.0000

 DEGREES OF FREEDOM           3
 CASES INCLUDED               5       MISSING CASES    0
```

```
                  WA VS MEANFLOW
WA

2.9 +
    :        +
    :                                +
    :
    :
2.0 +
    :
    :
    :
    :
1.1 +
    :           +
    :
    :
    :   +   +
0.2 +
    -+---------+---------+---------+---------+-
    0.0       0.3       0.6       0.9       1.2
    MEANFLOW X 10E3   5 CASES PLOTTED
```

```
                  SA VS MEANFLOW
SA

9.0 +
    :
    :                                +
    :
    :
6.0 +
    :
    :
    :
    :
3.0 +
    :
    :
    :
    :   +    +  +
0.0 +       +
    -+---------+---------+---------+---------+-
    0.0       0.3       0.6       0.9       1.2
    MEANFLOW X 10E3   5 CASES PLOTTED
```

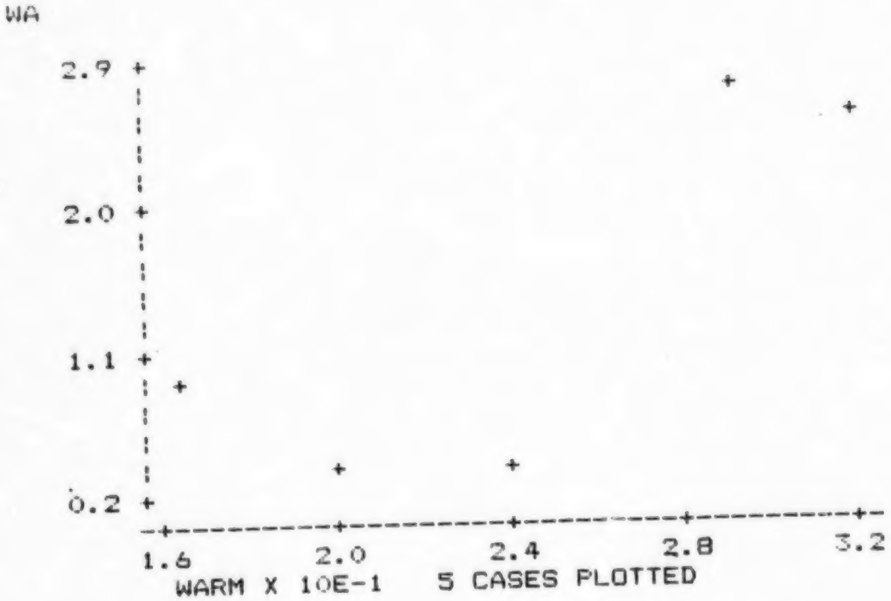
```
                       WA VS BIOWA
  WA

    2.9 +
        :                                   +
        :                      +
        :
        :
    2.0 +
        :
        :
        :
        :
    1.1 +
        : +
        :
        :
        : +  +
    0.2 +
        -+---------+---------+---------+---------+-
        0.0       0.3       0.6       0.9       1.2
         BIOWA X 10E3   5 CASES PLOTTED
```

```
                       SA VS BIOSA
  SA

    9.0 +
        :
        :                         +
        :
        :
    6.0 +
        :
        :
        :
        :
    3.0 +
        :
        :
        :
        :     +    +                          +
    0.0 +                            +
        -+---------+---------+---------+---------+-
        0.2       0.5       0.8       1.1       1.4
         BIOSA X 10E3   5 CASES PLOTTED
```

WA VS WARM



SA VS WARM